

**Argonne National Laboratory**

**PHYSICS DIVISION  
SUMMARY REPORT**

**October—December 1967**

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ARGONNE NATIONAL LABORATORY  
9700 South Cass Avenue  
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## PHYSICS DIVISION SUMMARY REPORT

October—December 1967

Lowell M. Bollinger, Division Director

### Preceding Summary Reports:

ANL-7354, Annual Review  
ANL-7355, April-June 1967  
ANL-7384, July-September 1967



## FOREWORD

The Physics Summary is issued several times per year for the information of the members of the Division and a limited number of other persons interested in the progress of the work. It includes short reports on highlights of the current research, abstracts or short summaries of oral presentations at meetings, abstracts of papers recently accepted for publication, and publication notices of papers appearing in recent journals and books. Many of these reports cover work still in progress; the results and data they present are therefore preliminary, tentative, and often incomplete.

The research presented in any one issue of the Summary is only a small random sample of the work of the Physics Division. For a comprehensive overview, the reader is referred to the ANL Physics Division Annual Review issued each summer, the most recent being Argonne National Laboratory Report ANL-7354 which reports research in the year ending 31 March 1967.

The issuance of these reports is not intended to constitute publication in any sense of the word. Final results will be submitted for publication in regular professional journals, or, in special cases, presented in ANL Topical Reports.

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## I. RESEARCH HIGHLIGHTS

These research highlights are Physics Division contributions to the Physical Research Monthly Report which the Laboratory Director's Office sends to the Division of Research of the U. S. Atomic Energy Commission. They report interesting work that is currently in progress or that has just been completed.

### DETERMINATION OF SPINS AND PARITIES OF LOW-ENERGY STATES FROM AVERAGE NEUTRON-RESONANCE-CAPTURE SPECTRA

L. M. Bollinger and G. E. Thomas

In many studies of neutron-capture gamma rays, the information content of the spectra is obscured by the random fluctuations in intensity that are characteristic of the primary transitions following thermal-neutron capture or capture in individual resonances. In late 1966 we first reported on a new class of measurements in which this problem is avoided by measuring directly the gamma-ray spectra that result from the capture of neutrons in an energy band containing many resonances. During the past year we have used such spectra in a variety of investigations. This report emphasizes the value of the average resonance-capture spectra for the study of low-energy nuclear states.

The average resonance-capture spectra are obtained by using a high-resolution Ge(Li)  $\gamma$ -ray spectrometer to measure the capture  $\gamma$  rays emitted by a  $B^{10}$ -surrounded sample that is placed in a high-flux region of a nuclear reactor. The boron selectively removes low-energy neutrons, and the  $1/E$  spectrum of the incident neutron flux assures a low intensity of energetic neutrons. The combination limits the energies of the neutrons captured in the sample to a band that is low enough to restrict the capture process to s-wave and perhaps p-wave interactions,

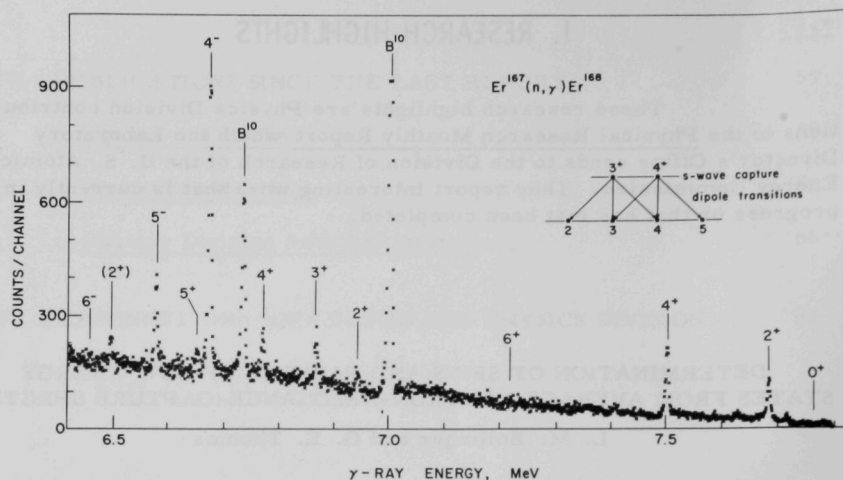
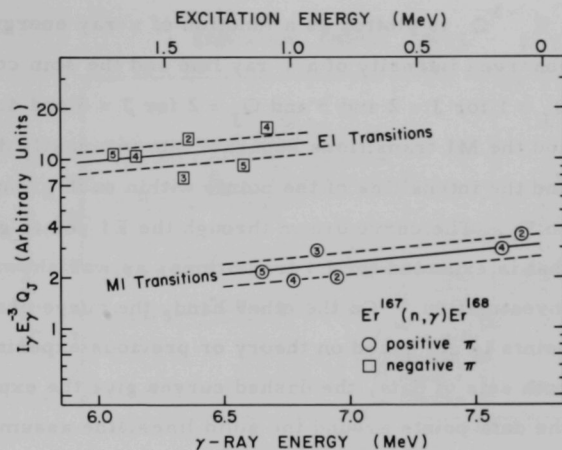


Fig. 1. A part of the average resonance-capture spectrum for the reaction  $\text{Er}^{167}(n, \gamma)\text{Er}^{168}$ . The diagram in the upper right shows the transition paths that are expected to have a detectable intensity. The label associated with each gamma-ray line gives the spin and parity of the final state fed by the transition. The position of the undetected ground-state transition is given by the label  $0^+$ .

narrow enough that it does not appreciably broaden the peaks in the spectrum from the high-resolution  $\text{Ge}(\text{Li})$  detector, but broad enough to contain many neutron resonances.

A representative average resonance-capture spectrum is given in Fig. 1. The diagram at the upper right shows how the spectrum is formed. Capture of s-wave neutrons (the only process of significant intensity in this case) forms initial states with spin  $J = 3$  or  $4$ . Thus, dipole radiation (the dominant process) can feed final states with  $J = 2, 3, 4$ , or  $5$ . For the case under consideration it can be shown on the basis of a simple statistical model of the radiation process that all of the transition paths shown on the diagram proceed with approximately equal intensity. Thus, the observed transitions to final states with  $J = 3$  or  $4$  are expected to be about twice as strong as transitions to final states with  $J = 2$  or  $5$ . Also, since electric-dipole

Fig. 2. Dependence of gamma-ray intensity on the parity of the final state.



transitions are an order of magnitude stronger than magnetic-dipole transitions for most nuclides, the E1 transitions to final states with negative parity are expected to be much more intense than the M1 transitions to positive-parity states. These conjectures form the essential basis for the use of average resonance-capture spectra to determine the spins and parities of the low-energy states.

The reaction  $\text{Er}^{167}(n, \gamma)\text{Er}^{168}$  was chosen for study as a test of the above ideas because the spins and parities of many low-energy states of  $\text{Er}^{168}$  were known from previous  $(n, \gamma)$  and  $(d, p)$  measurements.<sup>1,2</sup> These assignments are shown as labels attached to the  $\gamma$ -ray lines of Fig. 1. Examination of the spectrum shows that the expected pattern of intensity is at least qualitatively present. For example, the transition to the  $2^+$  first excited state (the peak at the extreme right) is only about half as strong as the transition to the nearby  $4^+$  state; also, all of the transitions to positive-parity states are much weaker than the transitions to the  $4^-$  and  $5^-$  states.

The expected dependence of the  $\gamma$ -ray intensity on the parity of the final state is examined quantitatively in Fig. 2. Here

<sup>1</sup>H. R. Koch, Z. Physik 192, 142 (1966).

<sup>2</sup>D. A. Harlan and R. K. Sheline, Phys. Rev. 160, 1005 (1967).

$I_{\gamma} E_{\gamma}^{-3} Q_J$  is plotted as a function of  $\gamma$ -ray energy  $E_{\gamma}$ , where  $I_{\gamma}$  is the observed intensity of a  $\gamma$ -ray line and the spin correction factor is  $Q_J = 1$  for  $J = 2$  and  $5$  and  $Q_J = 2$  for  $J = 3$  and  $4$ . The E1 transitions and the M1 transitions separate into two easily distinguishable groups, and the intensities of the points within each group seem to depend smoothly on  $E_{\gamma}$ . The curve drawn through the E1 points gives the  $E_{\gamma}^{-5}$  dependence that is expected for E1 transitions, as was shown in an earlier investigation.<sup>3</sup> On the other hand, the curve drawn through the M1 points is not based on theory or previous experimental evidence. For both sets of data, the dashed curves give the expected rms scatter of the data points around the solid lines, the assumption being that the only source of scatter is a random fluctuation caused by the Porter-Thomas distribution of partial radiation widths. The fact that the observed scatter is consistent with this assumption indicates that to within an uncertainty of about 10% the  $\gamma$ -ray intensities are independent of the details of the structure of the final state. Thus, as hoped, the measured intensity gives reliable information about the spins and parities of all final states.

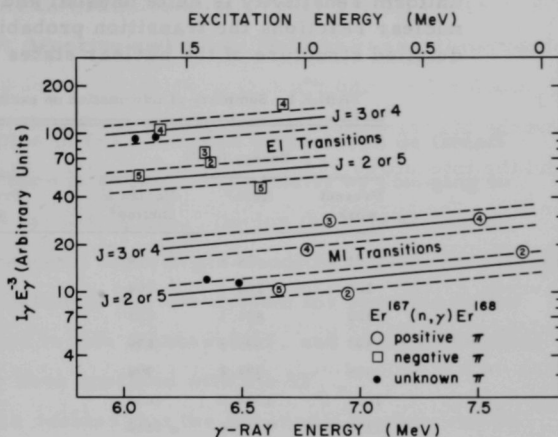
The spin dependence of the observed intensity is examined in Fig. 3, where  $I_{\gamma} E_{\gamma}^{-3}$  is plotted as a function of  $E_{\gamma}$ . Here the data points separate into the expected four groups and, with one exception, the intensities of states with  $J = 2$  or  $5$  are distinctly smaller than the intensities for states with  $J = 3$  or  $4$ . The one exception is the state labeled  $J = 3$  at an excitation energy of 1431 keV. Since the previous spin assignment of this state is quite uncertain, the discrepancy is not necessarily significant.

In view of the excellent agreement (for states with known spins and parities) between the observed intensities and what would be expected on the basis of a simple statistical model of the transitions,

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<sup>3</sup> L. M. Bollinger and G. E. Thomas, Phys. Rev. Letters 18, 1143 (1967).

Fig. 3. Dependence of gamma-ray intensity on the spin of the final state.



we may with confidence use the measured intensities to obtain information about the spins and parities of states for which these parameters are unknown. As is shown in Fig. 3, the intensities for these unknown states (black dots) fall unambiguously along one or another of the four curves and in this way provide the desired information.

The energies and parameters of the levels observed in our spectra are listed in Table I, along with those reported previously. The agreement is excellent for states observed previously, and the average resonance-capture measurements reveal the presence of several additional states.

On the basis of these measurements and of similar measurements for other nuclides, we conclude that the average resonance-capture spectra can be very useful in the study of low-energy nuclear states. In particular:

- (1) For most nuclides the parities of states fed by primary dipole transitions can be determined with certainty.
- 2) The spin of each such state can be determined within narrow limits.
- 3) When the measurement in a given range of energy is sensitive enough to reveal the presence of any state with a given spin and parity, then all states of that spin and parity can be observed. This

uniform sensitivity is quite unusual and useful, since in most nuclear reactions the transition probability depends on the detailed structure of the nuclear states involved.

TABLE I. Summary of information on excited states of  $\text{Er}^{168}$ .

Present work	Energy (keV)		$J^\pi$ assignments	
	Koch <sup>1</sup>	Harlan & Sheline <sup>2</sup>	Previous work	Present work
81	79.8	79	$2^+$	$2^+$ or $5^+$
265	264.1	264	$4^+$	$3^+$ or $4^+$
822	821.1	823	$2^+$	$2^+$ or $5^+$
897	895.8	899	$3^+$	$3^+$ or $4^+$
995	994.8	998	$4^+$	$3^+$ or $4^+$
1094*	1094.0	1094	$4^-$	$3^-$ or $4^-$
1117	1117.6	$\approx 1110$	$5^+$	$2^+$ or $5^+$
1194	1193.0	1193	$5^-$	$2^-$ or $5^-$
1277				$2^+$ or $5^+$
1403		1393	$2^-$	$2^-$ or $5^-$
1415				+
1431		1427	$3^-$	?
1541	1541.6	1542	$3^-$	$3^-$ or $4^-$
1568				$2^-$ or $5^-$
1572				$2^-$ or $5^-$
1614	1615.4	1615	$4^-$	$3^-$ or $4^-$
1632				$3^-$ or $4^-$
1671				+
1674				+
1707	1708.0	1709	$5^-$	$2^-$ or $5^-$
1718				$3^-$ or $4^-$

\* Reference energy.

## SULFUR HEXAFLUORIDE GAS-HANDLING SYSTEM

F. P. Mooring and J. R. Wallace

The operation of the converted tandem Van de Graaff accelerator has recently been improved substantially by changing to sulfur hexafluoride as the insulating gas. During the conversion of the EN tandem to an FN tandem, the old gas-handling system for nitrogen was removed. The installation of the new system for handling sulfur hexafluoride was completed in late October 1967, and since 23 October the converted tandem has been operated with the  $SF_6$ .

When it was decided that the EN-model tandem was to be converted to an FN-model tandem, a decision had to be made about modifying the accompanying gas-handling system. The EN pressure tank has a volume of 1640 cu ft, and the FN tank has a volume of 4600 cu ft. With the old EN machine, the turn-around time for transferring the insulating gas from the pressure tank to storage, venting to air, opening for repairs, closing, evacuating the air, and refilling to 225 psig was 9 hours. The increased volume of the FN tank would have increased this time to at least 24 hours. Such a loss of useful machine time would be too wasteful. To decrease the turn-around time to a reasonable value would require larger piping (3-in. diameter instead of 2-in.), a larger gas compressor, and another vacuum pump. In addition, the larger tank of the FN machine called for extra storage volume.

Since for all practical purposes a new gas-handling system had to be provided, it was decided to convert to sulfur hexafluoride as the insulating gas. Experience with using  $SF_6$  in an EN accelerator at Chalk River had shown that its insulating properties were superior to those of the mixture of nitrogen and carbon dioxide usually used in similar accelerators. Also Radiation Dynamics, Inc. had had good results with  $SF_6$  as the insulating medium in their Dynamitrons.

Furthermore, the high pressure (225 psig) required for the  $N_2$ - $CO_2$  mixtures led to alignment problems in the earlier FN-model tandems because of the stresses produced in the end plates of the pressure tanks. This problem would be greatly alleviated by changing to  $SF_6$ , which requires only  $\sim 60$  psig for the same degree of insulation.

Since 23 October 1967 when the installation of the new gas-handling system was completed, the insulating gas in the converted FN tandem has been  $SF_6$  at an operating pressure  $\leq 70$  psig. Storing the  $SF_6$  as a liquid considerably reduces the storage volume; and the relatively low storage pressure ( $\leq 600$  psig instead of the 2500 psig for the old  $N_2$ - $CO_2$  system) is an added safety feature.

The functions to be performed by the system are: (1) removing the  $SF_6$  from the pressure vessel, liquefying it, and transferring it to storage, (2) drying the  $SF_6$  during the transfer, while in the accelerator, or while in storage, (3) purging the liquid  $SF_6$  of noncondensable gases, (4) removing undesirable break-down products, (5) removing air from the pressure vessel of the accelerator, (6) transferring  $SF_6$  from a liquid in storage to a gas in the pressure vessel.

The turn-around time is 6—7 hours. The new valve system is much simpler to operate than the old one and should obviate most errors in gas handling. Since the system is leak tight, the loss of  $SF_6$  in the course of a transfer cycle is very small ( $< \$1.00$ ).

To date our experience with the use of  $SF_6$  has been favorable. The FN runs much more stably than with the  $N_2$ - $CO_2$  mixture. To an experimenter this means that his reaction rate remains more nearly constant and that his results are more reliable. To the operator it means that the machine remains in control, and that the beam energy can be changed much more easily. All in all, the use of the machine becomes much more efficient.

Sparking at all but the highest energies has been almost entirely eliminated. To reach any achievable terminal voltage, one

merely increases the charging current to the required value. Terminal voltages up to 8.5 MV are routinely possible and 9 MV has been achieved on several occasions. One run at 9.0 MV lasted for 15 hours. The charging currents required to reach a certain terminal voltage are usually less with  $\text{SF}_6$  than with  $\text{N}_2\text{-CO}_2$ . For example, to reach 7.5 MV with  $\text{N}_2\text{-CO}_2$  on various occasions has required charging currents of 295—320  $\mu\text{A}$ , whereas 310  $\mu\text{A}$  produced a terminal voltage of 9.0 MV with  $\text{SF}_6$ . This indicates that undesirable corona currents are suppressed by  $\text{SF}_6$ . The long-term effects cannot as yet be assessed, but experience at other laboratories indicates that few, if any, adverse effects are to be expected.

## BLOCKING OF CHARGED PARTICLES SCATTERED IN A MONOCRYSTAL

D. S. Gemmell and R. E. Holland

In early 1965 an experiment<sup>1</sup> at the Argonne Tandem revealed a new effect in which charged particles that in effect originate at atomic lattice sites in a monocrystal are "blocked" from escape in certain directions by collisions with atoms in neighboring lattice sites. During the two years since this discovery, the blocking effect has been thoroughly investigated both experimentally and theoretically. This report (based on a paper recently submitted for publication) summarizes our current understanding of an effect that is interesting in itself and may have future implications for several areas of physics.

When an energetic charged particle moves through a crystal, the effect of the crystal structure is most evident when the particle moves nearly parallel to a lattice plane with high symmetry (low Miller indices). If the incident particle strikes the crystal in such a direction, a series of small-angle scatterings by the lattice will confine it to the unobstructed channel between the lattice planes. Hence it never comes close enough to a nucleus to suffer a large-angle scattering. (In addition to these planar channels, there are also axial channels defined by the intersections of two sets of low-index planes.) Most previous studies have been concerned with planar and/or axial scattering. The research reported here, however, seeks to understand the motions of particles that in effect originate on lattice sites (within the lattice planes). These particles cannot be channeled; if they move parallel to a channel, they are blocked by the nearest neighbors in this lattice plane—if they start off in other directions, they are scattered almost at random.

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<sup>1</sup> D. S. Gemmell and R. E. Holland, Phys. Rev. Letters 14, 945 (1965).

We have studied this process of blocking with beams of particles (protons, deuterons, and alphas) from the Argonne tandem accelerator. As some of these particles enter the target lattice, they pass close enough to a nucleus to be deflected through a large angle. Because of the short-range nature of the scattering process, these scattered particles may be thought of as originating at a lattice site. The low-index directions in the lattice will be forbidden to these particles because of collisions with the nuclei in neighboring lattice sites. One aspect to which we devoted considerable attention was the angular width of the forbidden directions for blocked particles. We found that the widths, while smaller than that predicted by the distance of the nearest neighbor, were given within a factor 2 by models based on "smearing" the nuclei uniformly over an axis or plane. Calculations in which the paths of particles were traced through an idealized lattice also gave similar results.

Figure 4(a) shows a typical pattern obtained by allowing 4-MeV protons to be scattered by a monocrystal of silicon and impinge on a photographic plate. The white lines correspond to crystal planes; only planes of high symmetry are seen. Figure 4(b) shows the output from a computer program which calculated the lines along which the crystal planes (extended) intersect the plane of the photographic plate used to obtain Fig. 4(a). This plot shows the lines of intersection of all planes for which each of the three indices was  $\leq 8$ .

More quantitative information was obtained by using a solid-state detector with high angular resolution as shown in Fig. 5(a). Figure 5(c) is a typical pulse-height spectrum for the scattered protons. If the number of particles with more than normal energy loss is plotted as a function of the position of the detector, the plot shows dips as in Fig. 5(b) when the detector crosses a projection of the crystal planes. Figure 5(d) shows that particles with less than normal energy loss

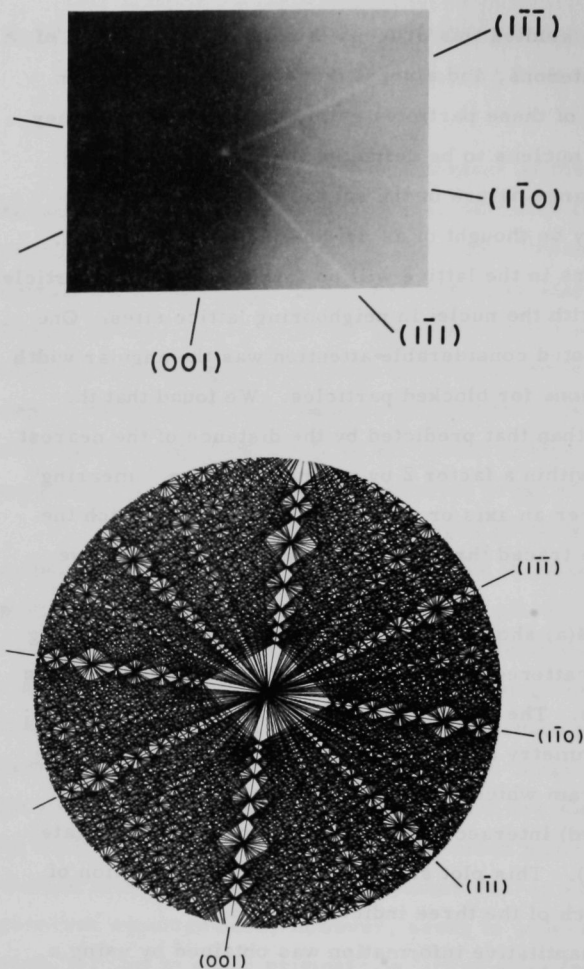


Fig. 4. The blocking of particles scattered in a monocrystal. (a) The pattern produced on a photographic plate exposed to 4-MeV protons scattered from a silicon crystal. The intersection of lines near the center of the figure corresponds to the  $\langle 110 \rangle$  axis, which made an angle of  $15^\circ$  with respect to the incident beam. The photographic plate is much darker on the left because of the strongly forward Rutherford scattering. (b) A computer-produced plot of the lines along which the crystal planes (extended) intersect a plane in the position of the photographic plate of Fig. 4(a). This figure plots all planes for which all three indices are  $\leq 8$ . Only the planes with low indices are observed experimentally.

(channeled particles) are also present and that their number increases at a crystal plane.

Figure 6 shows the results of scanning an angular region centered on the  $\langle 110 \rangle$  axis—the axis marked by the center of the star pattern in Fig. 4(a). Figure 6(a) represents the spatial distribution of particles with normal energy loss and Fig. 6(b) the particles with

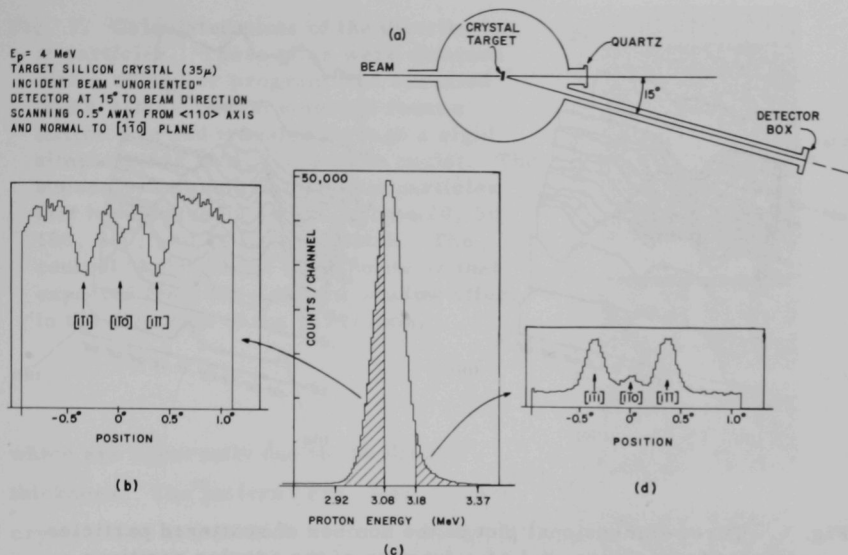


Fig. 5. "Position spectra" recorded with a detector. (a) The experimental arrangement with a movable detector. A computer was programmed to supervise the positioning of the detector and the accumulation and recording of data. (c) Energy spectrum of the scattered protons under the conditions of Fig. 4(a). Plot (b), the number of counts in the left-hand shaded portion of (c) as a function of the detector position, is the spatial distribution of the protons with less than the average energy (those with especially high energy loss in the lattice). Plot (d) is the spatial distribution of the low-loss (channeled) protons in the high-energy shaded tail of the peak in (c).

less than normal loss. Notice that, as in the photographic plate, the influence of the planes is reduced in the neighborhood of the axis.

A theory of channeling and blocking has been developed by Lindhard<sup>2</sup> and independently by Erginsoy.<sup>3</sup> They describe the motion of particles in a lattice in terms of an average potential obtained by smoothing the nuclear charge along a line or over a plane. Although the

<sup>2</sup> J. Lindhard, Phys. Letters **12**, 126 (1964); Kgl. Danske Videnskab. Selskab, Mat.-Fys. Medd. **34**, No. 14 (1965).

<sup>3</sup> C. Erginsoy, Phys. Rev. Letters **15**, 360 (1965).

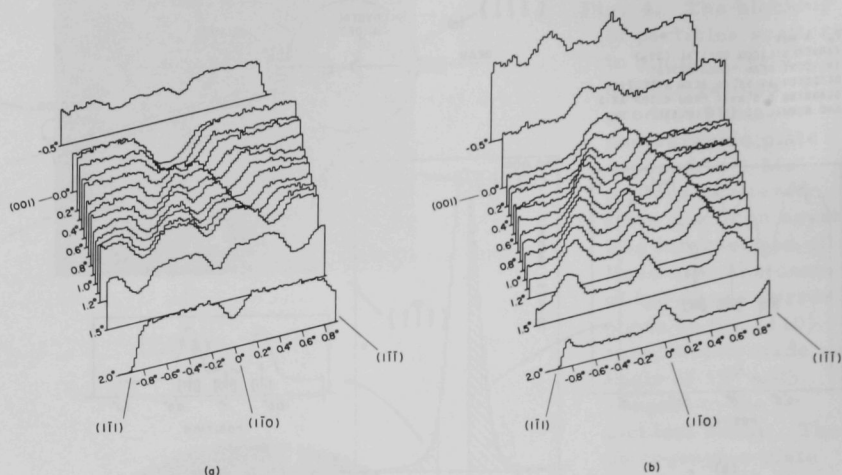


Fig. 6. Three-dimensional plot of the number of scattered particles emerging from the crystal as a function of the angular positions relative to the  $\langle 110 \rangle$  axis. The plots cover an angular range of  $2^\circ \times 2.5^\circ$  near the axis shown in Fig. 4(a). (a) The distribution of low-energy particles. (b) The distribution of high-energy particles.

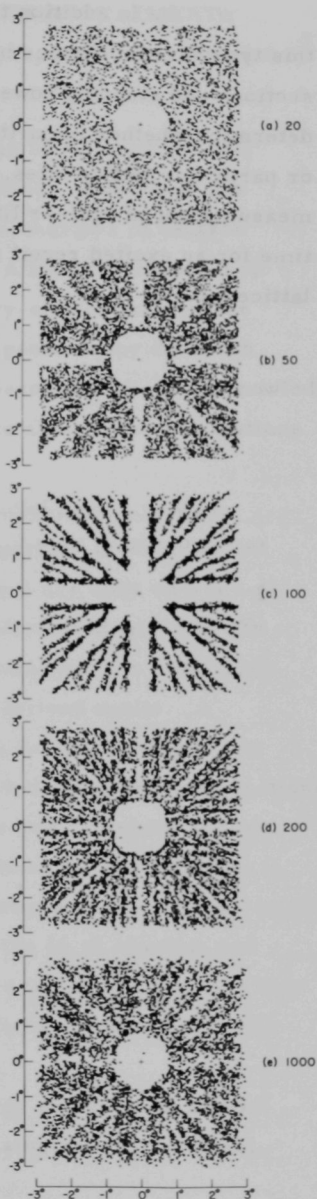
actual numerical values depend on the assumed parameters of the force between a particle and the lattice, these theories give line widths within a factor of 2 of those observed.

We have taken a different approach in which we assumed a highly simplified model of the crystal: the silicon nuclei were assumed fixed (no thermal motion and no recoil) in a cubic lattice with dimensions similar to those existing in a true silicon crystal. The screening effect of electrons was also neglected. Protons were assumed to emerge from a lattice site in a random direction near the  $\langle 100 \rangle$  axis and the paths of these protons through the lattice were calculated for various thicknesses of lattice. The results of this calculation are shown in Fig. 7, where each point represents the angular position of an emergent proton. These plots should be compared with the photographic plate of Fig. 4(a). For small thicknesses, the patterns display strong effects

Fig. 7. Calculated plots of the distribution of particles. These plots were obtained with a computer program that assumed that a 4-MeV proton emerged from a lattice site and traveled through a rigid simple-cubic lattice of silicon nuclei. The successive plots are made for particles that have passed through lattices 20, 50, 100, 200, and 1000 atoms thick. The central "hole" in the distribution is that expected from the Coulomb shadow effect in the direction of the  $\langle 100 \rangle$  axis.

which are apparently due to the limited thickness. The pattern [Fig. 7(e)] for a crystal 1000 atoms thick bears a strong resemblance to Fig. 4(a). The widths for planar blocking are about twice those observed experimentally, while the axial width is about five times that observed experimentally. This calculation also successfully reproduces the reduced blocking effect observed near the axis. In other measurements, it was verified that the line width varies, as expected, according to the inverse square root of the particle energy.

To summarize, the qualitative features of blocking phenomena are well explained by two quite different models. In view of the approximations in the models, it is not surprising that their quantitative predictions of the line width differ by a factor two from observation.



In addition to their intrinsic interest, experiments of this type have an obvious bearing on measurements of nuclear cross sections and stopping powers. Other investigators are using them to determine whether impurity atoms in a lattice occupy interstitial sites or particular lattice sites. Another possible application is the measurement of nuclear lifetimes in the range near  $10^{-17}$  sec—the time for an excited recoil nucleus to traverse the distance to a neighboring lattice site.

## REACTION SPECTROSCOPY IN THE HEAVY ELEMENTS

T. H. Braid, R. R. Chasman,<sup>\*</sup> J. R. Erskine, and A. M. Friedman<sup>\*</sup>

Reaction spectroscopy is proving to be a particularly valuable method of investigating nuclear structure. Both (d,p) and (d,t) reactions have been used to determine the energies of neutron single-particle states in the heavy elements. A fairly complete map of neutron single-particle energies in the heavy-element region has now been obtained by combining the reaction-spectroscopy data with information derived from conventional spectroscopic studies. A knowledge of these single-particle energies is essential to all detailed calculations of nuclear structure.

In the heavy-element region, nuclei have a prolate spheroidal shape. One consequence of this departure from spherical shape is that shell-model states of a given spin  $J$  are split into  $(J + \frac{1}{2})$  doubly degenerate states, each one having a different single-particle energy. A second consequence is that a rotational band is associated with each single-particle state in odd-mass deformed nuclei. A calculation of single-particle wave functions in an axially symmetric potential can be used to predict the (d,p) and (d,t) reaction cross sections for each member of the rotational band. Since this calculated pattern is relatively insensitive to the details of the potential, it constitutes a useful signature for identification of single-particle states. Furthermore, particle states are preferentially populated in the (d,p) reaction and hole states in the (d,t) reaction. These studies indicate in a direct way whether a given level is associated with a particle or hole state in the nucleus being studied.

In a nucleus, the observed energy of a level is shifted from the value that would be predicted from a single-particle model.

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<sup>\*</sup> Chemistry Division.



to nucleus indicates the approximate validity of a single-particle plus pairing model. The shifts which can be seen in the spectra will be valuable in a continuing attempt to refine the understanding of nuclear interactions.



## II. REPORTS AT MEETINGS

The abstracts and summaries that follow are not necessarily identical to those submitted for the meeting. In some cases, the authors have corrected or expanded abstracts; and summaries of contributed papers commonly have been shortened.

### Nuclear Physics Division of the American Physical Society

Madison, Wisconsin, 23—25 October 1967

#### GAMMA-RAY SPECTRA FROM $\text{Si}^{28,29,30}(\text{n}, \gamma)\text{Si}^{29,30,31}$ REACTIONS

G. B. Beard\* and G. E. Thomas

Bull. Am. Phys. Soc. 12, 1199 (December 1967)

The  $\gamma$ -ray spectra resulting from neutron-capture reactions in targets of separated isotopes of Si have been studied with a Ge(Li) spectrometer. Both singles spectra and runs in coincidence with the annihilation escape radiation have been obtained. Level assignments have been made on the basis of energy sums and relative  $\gamma$ -ray intensities. Preliminary analysis indicates levels at 1.274, 2.425, 4.935, 6.381, and 8.474 MeV for  $\text{Si}^{29}$ ; at 2.235, 3.497, 3.770, 6.774, and 10.610 MeV for  $\text{Si}^{30}$ ; and at 0.755, 2.2329, 4.382, and 6.590 MeV for  $\text{Si}^{31}$ . These proposed levels will be compared with those obtained by other studies of nuclear reactions.<sup>1,2</sup>

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\* Present address: Wayne State University, Detroit, Michigan.

<sup>1</sup> P. M. Endt and C. Van der Leun, Nucl. Phys. 34, 1 (1962).

<sup>2</sup> L. B. Hughes, Ph.D. thesis, McMaster University, 1967.

# DETERMINATION OF SPINS AND PARITIES OF LOW-ENERGY STATES FROM AVERAGE NEUTRON-RESONANCE CAPTURE SPECTRA

L. M. Bollinger and G. E. Thomas

Bull. Am. Phys. Soc. 12, 1200 (December 1967)

High-energy  $\gamma$  rays from thermal-neutron capture and capture in individual resonances are widely used to establish energies of low-energy nuclear states, but random intensity fluctuations limit their usefulness for spin and parity assignments. This problem is eliminated by a recently developed technique<sup>1</sup> in which the average spectrum from capture in many resonances is measured directly—as illustrated here for low-energy states in  $\text{Pd}^{106}$  and  $\text{Er}^{168}$ . For  $\text{Er}^{167}(n, \gamma)\text{Er}^{168}$ , primary transitions of a given multipolarity from initial  $3^+$  and  $4^+$  states formed by s-wave capture to final states with  $J = 2, 3, 4$ , or  $5$  are expected to have relative intensities  $1, 2, 2$ , or  $1$ , respectively. This expectation is satisfied by M1 transitions to known  $2^+, 3^+$ , and  $4^+$  low-energy states of  $\text{Er}^{168}$ . Negative-parity final states are easily identified because E1 transitions to them are about 6.5 times as strong as M1 transitions to positive-parity states of equal  $J$ . Average-capture lines for  $\text{Pd}^{105}(n, \gamma)\text{Pd}^{106}$  exhibit a similar dependence on spin and parity and, because of p-wave neutron capture, the  $\gamma$ -ray line shape depends strongly on final-state parity.

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<sup>1</sup> L. M. Bollinger and G. E. Thomas, Phys. Rev. Letters 18, 1143 (1967).

## EVIDENCE FOR INTERMEDIATE RESONANCE STRUCTURE IN THE SCATTERING OF NEUTRONS BY Fe

A. J. Elwyn and J. E. Monahan

Bull. Am. Phys. Soc. 12, 1186 (December 1967)

Two broad peaks that have widths of about 200 keV have been observed in the differential cross section and polarization of neutrons scattered from  $\text{Fe}^{56}$  at energies between 0.35 and 0.97 MeV. These

data, numerically averaged over a 100-keV interval, have been analyzed in terms of the intermediate-resonance model of nuclear reactions.<sup>1</sup> The preliminary results are that these peaks can be associated with two partially-overlapping s-wave excitations with total widths  $\Gamma \approx 150$  keV and partial widths  $\Gamma_{\uparrow} \approx 0.4 \Gamma$  for decay into the incident channel. Previous good-resolution measurements<sup>2</sup> of the total cross section reveal the existence of a large number of very narrow resonances in this energy interval. A sum rule (predicted by the intermediate model) that relates the widths of the fine-structure resonances to the width  $\Gamma_{\uparrow}$  was found to be approximately satisfied in the energy region near one of the intermediate-width peaks at which sufficient information about the fine structure is available.

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<sup>1</sup>H. Feshbach, A. K. Kerman, and R. H. Lemmer, Intermediate Structure and Doorway States in Nuclear Reactions, M.I.T. Report (unpublished).

<sup>2</sup>C. D. Bowman, E. G. Bilpuch, and H. W. Newson, Ann. Phys. (N.Y.) 17, 319 (1962).

### $K^{39}(\text{He}^3, p\gamma)\text{Ca}^{41}$ REACTION

D. S. Gemmell, L. Meyer-Schützmeister, H. Ohnuma, and N. G. Puttaswamy

Bull. Am. Phys. Soc. 12, 1183 (December 1967)

The gamma-decay properties of some  $\text{Ca}^{41}$  levels have been studied with the  $K^{39}(\text{He}^3, p\gamma)\text{Ca}^{41}$  reaction at  $E(\text{He}^3) = 12$  MeV. The target was made of natural KI evaporated on gold foil which stopped the  $\text{He}^3$  beam. The gammas were detected by a 25-cc Ge(Li) counter in coincidence with the protons at  $0^\circ$ . Such an arrangement restricts observation to those states in  $\text{Ca}^{41}$  that have even parity and dominant 2p-1h configuration<sup>1</sup>; we find that these states decay preferentially to

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<sup>1</sup>T. A. Belote, F. T. Dao, W. E. Dorenbusch, J. Kuperus, J. Rapaport, and S. M. Smith, Nucl. Phys. A102, 462 (1967).

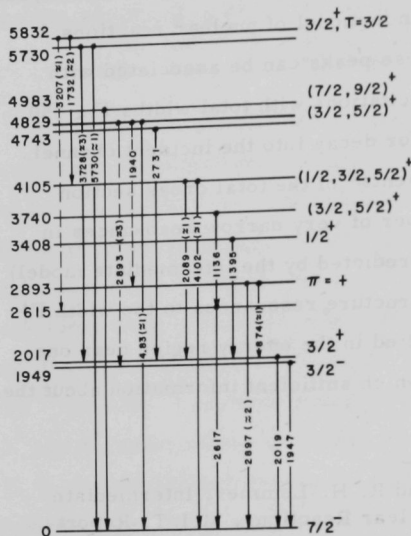


Fig. 9. The gamma decay of some  $\text{Ca}^{41}$  levels.

similar states, although in some cases strong transitions to the ground state ( $J^\pi = \frac{7}{2}^-, T = \frac{1}{2}$ ) have been observed. Most of the strong  $\gamma$  transitions could be associated with known levels in  $\text{Ca}^{41}$ . They are shown in Fig. 9 together with the spin assignments given by Endt and Van der Leun.<sup>2</sup> The associations of a few strong  $\gamma$  rays, shown by dashed lines, were doubtful. The relative strengths of the gammas (indicated by the numbers in parentheses) were estimated by measuring the p- $\gamma$  coincidences at three angles ( $30^\circ$ ,  $60^\circ$ ,  $90^\circ$ ) between the  $\gamma$  detector and the

incident  $\text{He}^3$  beam. The observed strengths of the gammas do not contradict those spin assignments which had been established definitely, but they exclude the possible spin assignment of  $\frac{1}{2}^+$  for the 4.105-MeV level. The analog state at 5.83 MeV ( $\frac{3}{2}^+, \frac{3}{2}$ ) decays mainly to the 4.11-MeV state and not to the 2.02-MeV state ( $\frac{3}{2}^+, \frac{1}{2}$ ) believed to be the "antianalog" of the 5.83-MeV state.

<sup>2</sup>P. M. Endt and C. Van der Leun, Nucl. Phys. A105, 1-488 (1967).

SMALL-ANGLE SCATTERING OF NEUTRONS BY HEAVY NUCLEI  
F. T. Kuchnir, A. J. Elwyn, A. Langsdorf, Jr., and F. P.  
Mooring

Bull. Am. Phys. Soc. 12, 1187 (December 1967)

We have measured the differential cross section and the polarization in the elastic scattering of 0.6—1.2-MeV neutrons by W, Au, Pb, U, and Th at a number of angles between  $1.75^\circ$  and  $15^\circ$ . The measured polarizations are negative and reach maximum values of 0.4—0.6 at  $1.75^\circ$  for all the nuclei and at all energies. Both the differential cross sections and the polarizations are compared with calculations that are based on an optical-model description of the nuclear scattering and that also include the interactions between the Coulomb field of the nucleus and the magnetic moment (Schwinger scattering) and the induced electric dipole moment (polarizability) of the neutron. Preliminary results indicate that the experimental data—both differential cross section and polarization—are consistent with the assumption that at these energies the nuclear interaction and the known electromagnetic interactions dominate the scattering at small angles.

POLARIZATION AND DIFFERENTIAL CROSS SECTION FOR NEUTRONS  
SCATTERED FROM  $^{12}\text{C}$

R. O. Lane, \* A. J. Elwyn, F. P. Mooring, J. E. Monahan,  
and A. Langsdorf, Jr.

Bull. Am. Phys. Soc. 12, 1185-1186 (December 1967)

Measurements of polarization  $P(\theta)$  and differential cross section  $\sigma(\theta)$  for neutrons scattered from  $^{12}\text{C}$  were obtained at 5—9 angles at each of 38 neutron energies from 0.5 to 2.0 MeV. The reaction  $^7\text{Li}(p,n)^7\text{Be}$  provided the partially polarized beam of neutrons and a spin-precession magnet was employed to obtain the asymmetry. The

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shape of  $P(\theta)$  is made up of a nearly constant term in  $\sin \theta$  and a steadily increasing one in  $-\sin 2\theta$  so that  $P(120^\circ) \approx 0.4$  near  $E_n \approx 1.9$  MeV. The term in  $\sin \theta$  is fitted by split constant terms in the R functions for  $\frac{1}{2}^-$  and  $\frac{3}{2}^-$ . The term in  $-\sin 2\theta$  is caused by interference between the  $S_{1/2}$  phase shift (which has a large contribution from the bound  $\frac{1}{2}^+$  state at  $E_{\text{ex}} = 3.09$  MeV in  $^{13}\text{C}$ ) and the relatively strong  $D_{3/2}$  phase shift produced by the broad  $\frac{3}{2}^+$  states in  $^{13}\text{C}$  at  $E_{\text{ex}} = 7.64$  MeV and 8.33 MeV. Rather good simultaneous fits to all the  $\sigma(\theta)$  and  $P(\theta)$  in this region have been obtained in terms of the R-function formalism for states in  $^{13}\text{C}$ .

#### APPLICATION OF A SELF-INDICATION METHOD TO THE MEASUREMENT OF NEUTRON ABSORPTION, TOTAL CROSS SECTION, AND THE VARIANCE OF THE TOTAL CROSS SECTION

F. P. Mooring and J. E. Monahan

Bull. Am. Phys. Soc. 12, 1187 (December 1967)

By use of a self-indication method, the energy-averaged total cross section and the variance of the total cross section have been simultaneously measured as a function of the energy of neutrons incident on targets of Mo, Ag, Sn, and Au. In addition, average values of the neutron absorption cross section for Ag and Au were obtained. The averaging interval corresponds to a spread of about 8 keV in the energy of the incident neutron beam. The strength functions for the elements studied were extracted by use of relations (based on a statistical model of nuclear reactions) that express the neutron and the gamma-ray strength functions in terms of the measured absorption cross sections and variances of the total cross section. The present results for the strength functions are compared with those obtained by other methods.

# THE J DEPENDENCE OBSERVED AT SMALL ANGLES IN THE $(d, \text{He}^3)$ REACTION

H. Ohnuma and J. L. Yntema

Bull. Am. Phys. Soc. 12, 1188 (December 1967)

The  $(d, \text{He}^3)$  reaction on even-mass Mo isotopes was experimentally investigated with the 23-MeV deuteron beam from the Argonne cyclotron. The targets were isotopically enriched metallic foils, and the detection system consisted of surface-barrier Si counters. Experimentally, the  $\ell=1$  angular distributions (Figs. 10 and 11) have

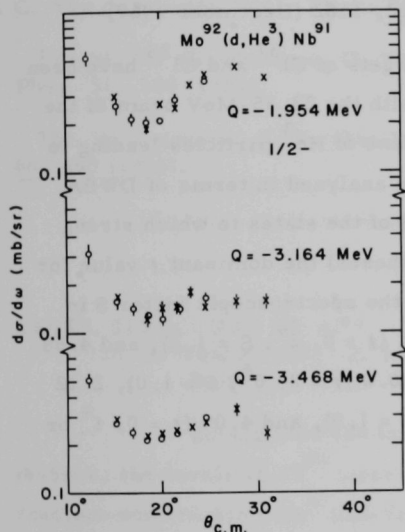


Fig. 10. The  $\ell=1$  angular distributions from the  $\text{Mo}^{92}(d, \text{He}^3)\text{Nb}^{91}$  reaction.

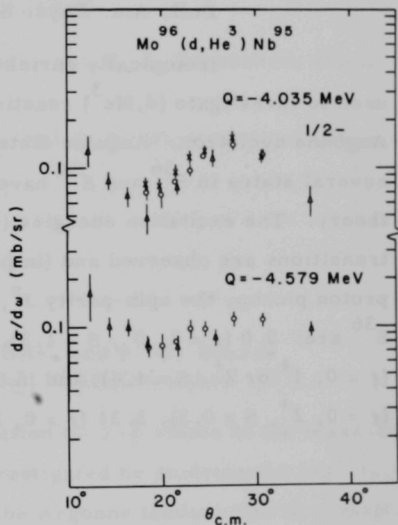


Fig. 11. The  $\ell=1$  angular distributions from the  $\text{Mo}^{96}(d, \text{He}^3)\text{Nb}^{95}$  reaction.

shallower minima around  $20^\circ$  for all the  $p_{3/2}$  transitions than for the  $p_{1/2}$  transitions. This difference was observed over a wide range of  $Q$  values. The DWBA calculations correctly predicted the experimental effect. It was found that the spin-orbit term in the deuteron optical potential caused this effect, in agreement with the results of

Freedom et al.<sup>1</sup> No significant  $j$  dependence was experimentally observed nor theoretically predicted in the  $(d,t)$  reactions on Mo isotopes.

<sup>1</sup> B. M. Freedom, E. Newman, and J. C. Hiebert, Phys. Letters 22, 657 (1966).

### ENERGY LEVELS OF $S^{36}$ AND $S^{34}$

N. G. Puttaswamy and J. L. Yntema

Bull. Am. Phys. Soc. 12, 1182 (December 1967)

Isotopically enriched targets of  $Cl^{37}$  and  $Cl^{35}$  have been used to investigate  $(d, He^3)$  reactions with the 23.35-MeV beam of the Argonne cyclotron. Angular distributions of  $He^3$  particles leading to several states in  $S^{36}$  and  $S^{34}$  have been analyzed in terms of DWBA theory. The excitation energies (MeV) of the states to which strong transitions are observed and (in parentheses) the dominant  $\ell$  value for proton pickup, the spin-parity  $J^\pi$ , and the spectroscopic factor  $S$  in  $S^{36}$  are: 0.0 ( $\ell = 2$ ,  $0^+$ ,  $S = 1.3$ ), 3.31 ( $\ell = 0$ ,  $2^+$ ,  $S = 1.2$ ), and 4.58 ( $\ell = 0$ ,  $1^+$  or  $2^+$ ,  $S = 1.4$ ); and in  $S^{34}$ : 0.0 ( $\ell = 2$ ,  $0^+$ ,  $S = 1.0$ ), 2.12 ( $\ell = 0$ ,  $2^+$ ,  $S = 0.3$ ), 3.31 ( $\ell = 0$ ,  $2^+$ ,  $S = 1.0$ ), and 4.09 ( $\ell = 0$ ,  $1^+$  or

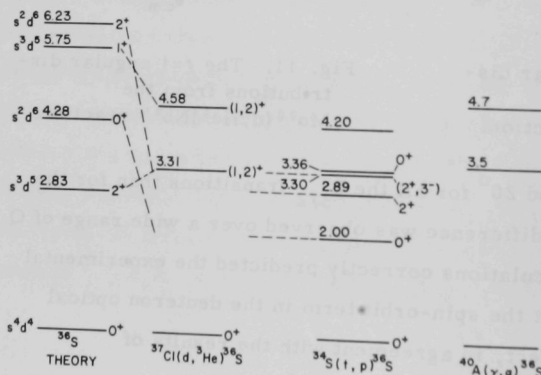


Fig. 12. Energy levels of  $S^{36}$  as seen in the  $(d, He^3)$ ,  $(t, p)$  (Ref. 1), and  $(\gamma, \alpha)$  (Ref. 3) reactions. The theoretical predictions are from Ref. 2. Dotted lines indicate possible connections among the various results.

$2^+$ ,  $S = 0.7$ ). In the above analysis, the results of (t,p) reactions<sup>1</sup> on  $S^{34}$  and  $S^{32}$  have been used whenever a  $2^+$  assignment is made for an  $\ell=0$  pickup. The states at 4.58 MeV in  $S^{36}$  and 4.09 MeV in  $S^{34}$  may be the  $1^+$  states predicted at 5.75 and 4.97 MeV, respectively, from shell-model calculations.<sup>2</sup> The energy levels of  $S^{36}$  as seen by the various reactions<sup>1,3</sup> are compared with theoretical predictions<sup>2</sup> in Fig. 12.

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<sup>1</sup>S. Hinds and R. Middleton (private communication); P. M. Endt and C. Van der Leun, Nucl. Phys. A105, 1 (1967).

<sup>2</sup>P. W. M. Glaudemans, G. Wiechers, and P. J. Brussaard, Nucl. Phys. 56, 548 (1964).

<sup>3</sup>M. A. Reimann, J. R. MacDonald, and J. B. Warren, Nucl. Phys. 66, 465 (1965).

## LEVEL STRUCTURE OF $Al^{29}$

D. H. Youngblood,\* J. L. Yntema, and R. C. Bearse  
Bull. Am. Phys. Soc. 12, 1181 (December 1967)

To augment the information on  $T=\frac{3}{2}$  states in the mass-29 isobars, the levels in  $Al^{29}$  were reinvestigated by studying the  $Mg^{26}(a,p)Al^{29}$  reaction with 11-MeV  $He^4$  ions from the Argonne tandem Van de Graaff incident upon an isotopically pure, rolled  $Mg^{26}$  foil. The protons were detected in a magnetic spectrograph. Our excitation energies agree with those of Jaffe *et al.*<sup>1</sup> through the 11th excited state, except that for the 3rd excited state we obtain an excitation energy of  $2.228 \pm 0.005$  MeV. A comparison between their Fig. 5 and the table accompanying it indicates that their value is a misprint. The ground state and 1st

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\*Present address: The Cyclotron Institute, Texas A & M University, College Station, Texas.

<sup>1</sup>A. A. Jaffe, F. DeS. Barros, P. D. Forsyth, J. Mato, I. J. Taylor, and S. Ramavataram, Proc. Phys. Soc. (London) 76, 914 (1960).

excited state were studied further via the  $\text{Si}^{30}(\text{d}, \text{He}^3)$  reaction with 23-MeV deuterons from the Argonne cyclotron. The  $\ell=2$  angular distribution of the ground state agrees with the  $\frac{5}{2}^+$  assignment of Ref. 1. The observation that the 1st excited state has an  $\ell=0$  angular distribution indicates that the state has  $J^\pi = \frac{1}{2}^+$ . A comparison with distributions obtained with the code JULIE gives spectroscopic factors of 5.6 and 0.8 for the ground state and 1st excited state, respectively.

Annual Meeting of the Meteoritical SocietyAmes Research Center, Moffett Field, California, 25—27 October 1967OLIVINE AND PYROXENE IRON IN HYPERSTHENE CHONDRITES  
AS DETERMINED BY THE MÖSSBAUER EFFECT

E. L. Sprenkel-Segel

The recoilless resonant interaction of 14.4-keV gamma rays in  $\text{Fe}^{57}$  was used to study the iron minerals in hypersthene chondrites. The technique was similar to that described previously.<sup>1</sup> The ratio of olivine iron to pyroxene iron was calculated from the relative absorption intensities of the two minerals in an unseparated meteorite sample and the recoilless fractions determined for chemically analyzed minerals. For the meteorites Bruderheim, New Concord, Mocs, and Kyushu, the olivine/pyroxene iron ratios cluster about 2.2 and appear to vary—although the variation is within the range of experimental error. The ratio of olivine iron to pyroxene iron may be combined with the electron-microprobe analyses of iron and magnesium in the separated minerals to obtain the number of formula units of pyroxene relative to olivine in the unseparated sample. This ratio is of importance to theories for the origin of the ordinary chondrites and will be compared with the value for the bronzite chondrites.<sup>1</sup>

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<sup>1</sup>E. L. Sprenkel-Segel and G. J. Perlow, *Icarus* (in press, 1967).

American Physical Society, Division of Plasma Physics  
Austin, Texas, 8—11 November 1967

PERSEVERANCE OF NORMAL MODES IN A PLASMA-LOADED RESONANT CAVITY

A. J. Hatch, S. L. Halverson,<sup>\*</sup> and A. E. Froehlich

A discharge plasma is excited in the vicinity of the maximum electric field in the  $TE_{111}$  mode of a cylindrical cavity at the empty-cavity frequency of 620 MHz. The frequency of the cw rf power source is then shifted upward while maintaining the discharge in the cavity and keeping an impedance match between the plasma-loaded cavity and the power source. Plasma-maintaining conditions in the cavity are critically dependent on the impedance-matching adjustments and power level. Frequency shifting is greatly facilitated by use of an automatic impedance plotter to monitor the matching status and by a sustaining rf power source exciting the  $TM_{010}$  mode at an appropriate frequency. Thus if excitation of the discharge by the primary power source (a klystron amplifier with a  $\frac{1}{2}\%$  band width) is inadvertently lost, the discharge can be maintained (at a slightly reduced plasma density) by the sustaining source while restoring adjustments are made in the primary source. This technique has been used to obtain a shift of +4% in the frequency of the  $TE_{111}$  mode with plasma.

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<sup>\*</sup> Electronics Division.

American Physical Society  
New York, 16—18 November 1967

CAPTURE-GAMMA-RAY SPECTRUM OF  $\text{Te}^{123}(n, \gamma)\text{Te}^{124}$  AND THE  
 ASSOCIATED ENERGY LEVELS IN  $\text{Te}^{124}$

R. P. Chaturvedi,\* D. Bushnell,† and R. K. Smither  
 Bull. Am. Phys. Soc. 12, 1064 (November 1967)

The  $\gamma$  spectrum from the  $\text{Te}^{123}(n, \gamma)\text{Te}^{124}$  reaction on natural and enriched targets were measured with Ge(Li) detectors and with the Argonne bent-crystal spectrometer. The 54 observed lines

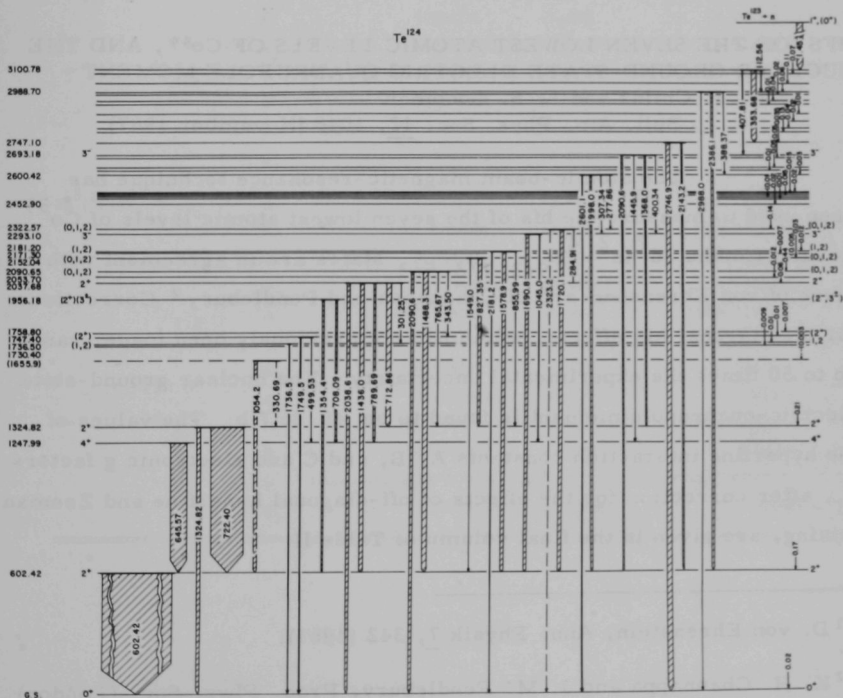


Fig. 13. Energy levels of  $^{124}\text{Te}$  produced in the  $^{123}\text{Te}(n, \gamma)$  reaction.

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† Permanent address: Northern Illinois University, DeKalb, Illinois.

between 5.5—9.5 MeV and 170 between 0.1 and 4.0 MeV were used to construct the level scheme of  $\text{Te}^{124}$  with 37 excited states below 3.1 MeV, as shown in Fig. 13. The parentheses indicate uncertain levels and spin assignments. The relative intensities of  $\gamma$  rays from states at  $\sim 2$  MeV suggest that E2 transitions to the two-phonon states at 1248 and 1325 keV are enhanced relative to those to states at 0 and 602 keV; so these 2-MeV levels are collective and possibly vibrational. The  $(n, \gamma)$  data imply a neutron binding energy of  $9424.9 \pm 2.0$  keV for  $\text{Te}^{124}$ .

#### HFS OF THE SEVEN LOWEST ATOMIC LEVELS OF $\text{Co}^{59}$ , AND THE NUCLEAR GROUND-STATE ELECTRIC QUADRUPOLE MOMENT

W. J. Childs and L. S. Goodman

Bull. Am. Phys. Soc. 12, 1046 (November 1967)

The atomic-beam magnetic-resonance technique has been used to measure the hfs of the seven lowest atomic levels of  $\text{Co}^{59}$ . Results for the  $3d^7 4s^2 4F_{9/2, 7/2, 5/2}$  states are in agreement with those of von Ehrenstein<sup>1</sup> and of Channappa and Pendlebury.<sup>2</sup> Corrections for off-diagonal hfs effects, which had not previously been made, range up to 50 times the experimental uncertainty. The nuclear ground-state electric-quadrupole moment is found to be  $+0.36(7)b$ . The values of the hyperfine interaction constants A, B, and C and electronic g factors  $g_J$ , after correction for the effects of off-diagonal hyperfine and Zeeman mixing, are given in the final column of Table II.

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<sup>1</sup> D. von Ehrenstein, Ann. Physik 7, 342 (1961).

<sup>2</sup> K. H. Channappa and J. M. Pendlebury, Proc. Phys. Soc. (London) 86, 1145 (1965).

TABLE II

State	Quantity measured	Observed (uncorrected) value (Mc/sec)	Correction (Mc/sec)	Corrected experimental value (Mc/sec)	
$3d^7 4s^2$	$4F_{9/2}$	A	450.287(1)	-0.004	450.283(1)
		B	139.655(30)	-0.425	139.230(30)
		C	0.001(3)	-0.001	0.000(3)
"	$4F_{7/2}$	$g_J$	1.33291(2)	-0.00002	1.33289(2)
		A	490.580(2)	-0.013	490.567(2)
		B	95.099(36)	-0.598	94.501(36)
"	$4F_{5/2}$	C	0.002(4)	-0.002	0.000(4)
		$g_J$	1.23781(2)	-0.00003	1.23778(2)
		A	613.376(3)	-0.027	613.349(3)
"	$4F_{3/2}$	B	68.232(43)	-0.691	67.541(50)
		C	0.001(3)	-0.003	-0.002(3)
		$g_J$	1.02827(2)	-0.00001	1.02826(2)
"	$4F_{3/2}$	A	1043.007(1)	-0.026	1042.981(1)
		B	67.266(12)	+0.352	67.618(20)
		C	(Assumed to be 0; only 2 hyperfine intervals measured.)		
	$g_J$	0.39911(2)	+0.00029	0.39940(2)	
$3d^8 ({}^3F)4s$	$4F_{9/2}$	A	828.808(1)	-0.009	828.799(4)
		B	-117.633(25)	-1.118	-118.751(300)
		C	0.004(3)	-0.002	0.002(4)
"	$4F_{7/2}$	$g_J$	1.33340(2)	+0.00003	1.33343(4)
		A	668.933(1)	-0.014	668.919(3)
		B	-79.248(38)	+0.027	-79.221(200)
"	$4F_{5/2}$	C	0.005(4)	-0.001	0.004(4)
		$g_J$	1.23658(2)	+0.00003	1.23661(4)
		A	562.203(2)	-0.020	562.183(3)
"	$4F_{5/2}$	B	-54.902(21)	+0.096	-54.806(250)
		C	(Assumed to be 0; only 2 hyperfine intervals measured.)		
		$g_J$	1.02708(2)	+0.00001	1.02709(4)

# LEVEL SCHEME OF $\text{Sm}^{153}$ BASED ON $(n, \gamma)$ , $(n, e^-)$ , AND $(\beta, \gamma)$ EXPERIMENTS

R. K. Smither, E. Bieber,<sup>\*</sup> T. v. Egidy,<sup>†</sup> W. Kaiser,<sup>†</sup> and K. Wien<sup>‡</sup>

Bull. Am. Phys. Soc. 12, 1065 (November 1967)

The  $\text{Sm}^{152}(n, \gamma)\text{Sm}^{153}$  spectrum was measured with the Argonne bent-crystal spectrometer and with a Ge(Li) detector at the in-pile facility at the Argonne CP-5 research reactor. The low-energy bent-crystal spectrum consisted of 146 gamma transitions associated with thermal-neutron capture in  $\text{Sm}^{152}$  and with energies between 35 keV and 800 keV. The identification with the  $\text{Sm}^{152}(n, \gamma)\text{Sm}^{153}$  reaction was made by comparing relative gamma intensities from three neutron-capturing samples—the first being enriched in  $\text{Sm}^{149}$ , the second in  $\text{Sm}^{150}$ , and the third in  $\text{Sm}^{152}$ . The gamma-ray intensities were normalized to the previously established intensity of the 103-keV line in  $\text{Eu}^{153}$  from the  $\beta$  decay of  $\text{Sm}^{153}$ . The energies and intensities of 24 other lines measured with the bent-crystal spectrometer and associated with this  $\beta$  decay are also given to facilitate comparison with previously published work. The high-energy portion of the  $(n, \gamma)$  spectrum obtained with the Ge(Li) detector contained 35 lines with energies between 5.2 and 6.3 MeV.

The energy differences between the high-energy gamma rays, often good to 0.1–0.2 keV, were used to suggest the energies of many of the low-lying states in  $\text{Sm}^{153}$ . The precision energy measurements of the low-energy gammas with the bent-crystal spectrometer were then used to develop this level scheme and to obtain the details of the  $\gamma$ -decay branching ratios and to define the level energies to

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<sup>\*</sup>Present address: Carl Zeiss, Inc., New York, New York.

<sup>†</sup>Technischen Hochschule München, Germany.

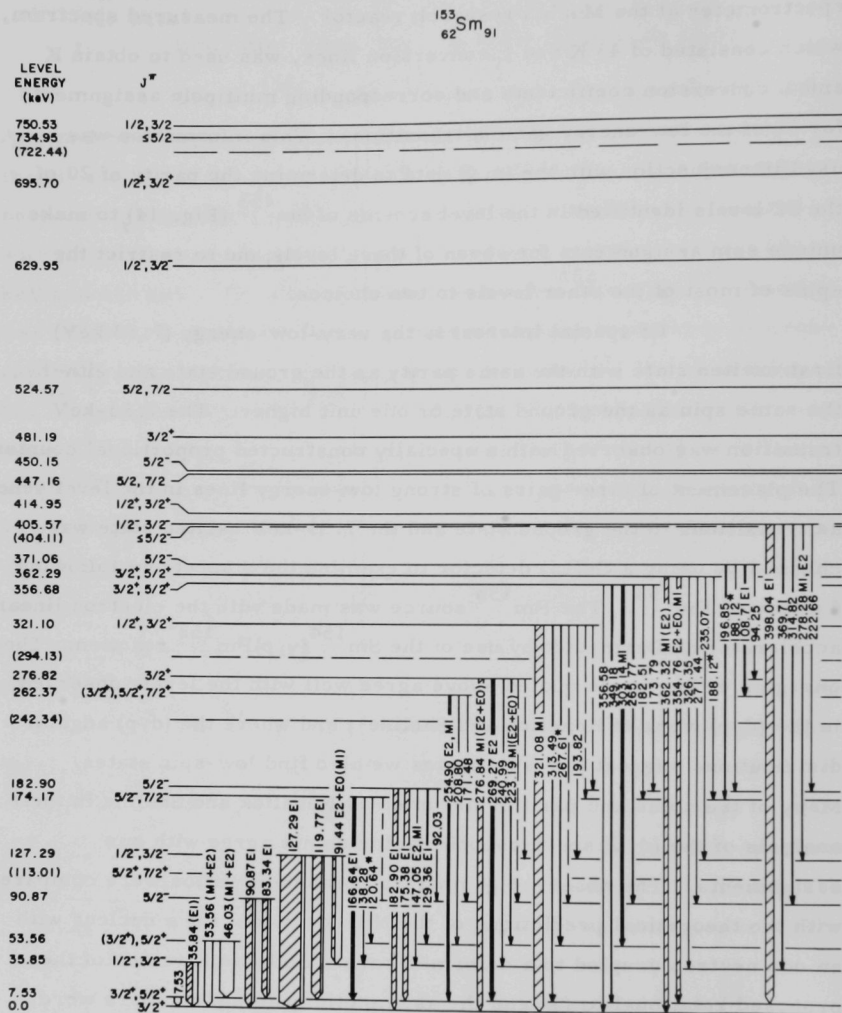
<sup>‡</sup>Technischen Hochschule Darmstadt, Germany.

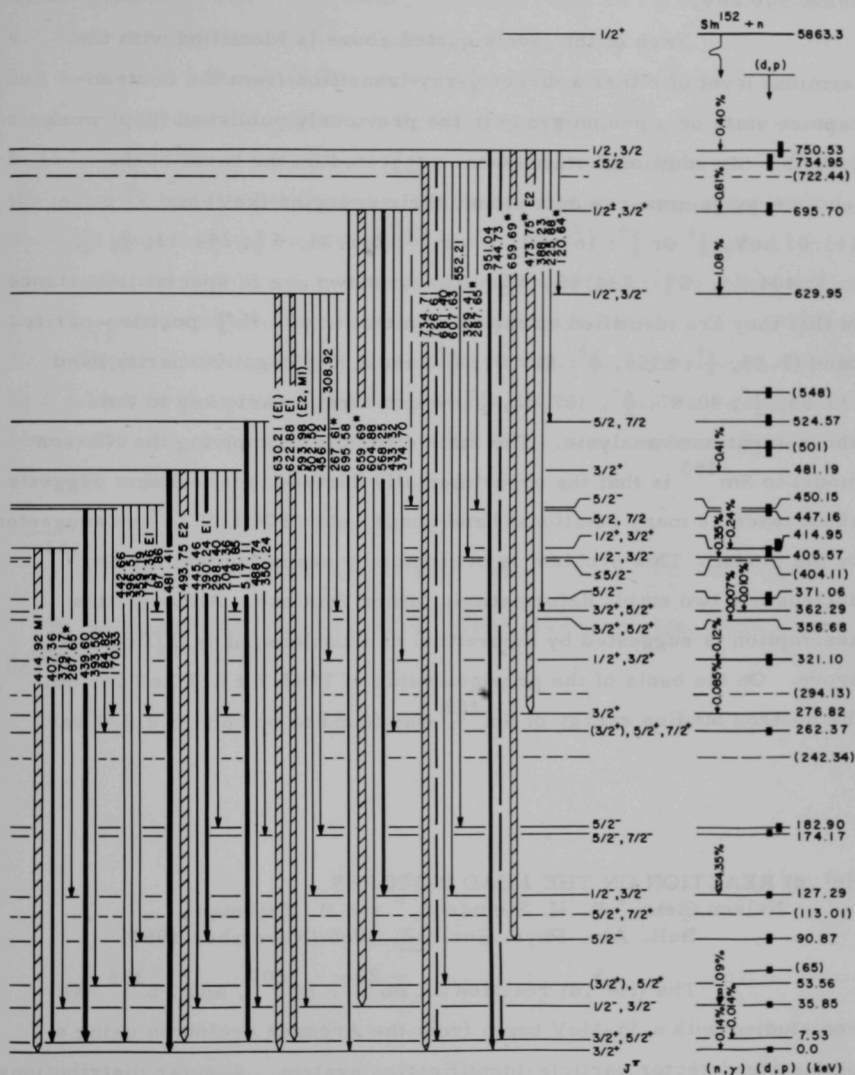
$\pm 0.01 - 0.03$  keV. The conversion-electron spectrum resulting from  $\text{Sm}^{152}(n, e^-)\text{Sm}^{153}$  was measured with the high-resolution magnetic spectrometer at the Munich research reactor. The measured spectrum, which consisted of 43 K and L conversion lines, was used to obtain K and L conversion coefficients and corresponding multipole assignments for 30 of the low-energy gamma transitions. This information was used in conjunction with the  $(n, \gamma)$  data to determine the parity of 20 of the 32 levels identified in the level scheme of  $\text{Sm}^{153}$  (Fig. 14), to make unique spin assignments for seven of these levels, and to restrict the spins of most of the other levels to two choices.

Of special interest is the very-low-energy (7.53 keV) first excited state with the same parity as the ground state and either the same spin as the ground state or one unit higher. The 7.53-keV transition was observed with a specially constructed proportional counter. The placement of three pairs of strong low-energy lines in the level scheme as transitions to the ground state and the 7.53-keV excited state was checked by using a Ge(Li) detector to examine the  $\gamma$  spectrum following  $\beta$  decay of  $\text{Pm}^{153}$ . The  $\text{Pm}^{153}$  source was made with the electron linear accelerator at Darmstadt by use of the  $\text{Sm}^{154}(\gamma, p)\text{Pm}^{153}$  reaction. The energies of the levels quoted above agree well with the levels observed in the  $(d, p)$  work of Kenefick and Sheline<sup>1</sup>; and where the  $(d, p)$  angular distributions suggest low-spin states we also find low-spin states. Many of the spins and parities assumed by Kenefick and Sheline in their analysis of the  $(d, p)$  spectroscopic factor do not agree with our assignments. The observed gamma-ray branching ratios were compared with the theoretical predictions of the Nilsson model for a nucleus with an odd neutron coupled to a deformed core. Both the K values of the proposed rotational bands and the asymptotic quantum numbers were taken into account in this analysis, and consistent but not unique

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<sup>1</sup>R. A. Kenefick and R. K. Sheline, Phys. Rev. 139, B1479 (1965).

Fig. 14. Energy level scheme of  $\text{Sm}^{153}$ . The widths of the



arrows indicate the intensities of the  $\gamma$ -ray transitions.

assignments of  $J^\pi$ , K, and  $[N, n_z, \Lambda]$  were found for most of the levels below 500 keV.

Each of the levels quoted above is identified with the terminal level of either a direct  $\gamma$ -ray transition from the neutron-capture state or a proton group in the previously published (d, p) work or both. Six additional states were suggested on the basis of the low-energy gamma-ray data alone, their energies (keV) and  $J^\pi$  were: 113.01 keV,  $\frac{5}{2}^+$  or  $\frac{7}{2}^+$ ; 167.82,  $\frac{5}{2}^-$  or  $\frac{7}{2}^-$ ; 242.34,  $\leq \frac{7}{2}$ ; 294.13,  $\frac{3}{2}$ ,  $\frac{5}{2}$ , or  $\frac{7}{2}$ ; 404.11,  $\leq \frac{5}{2}$ ; 734.95,  $\leq \frac{5}{2}$ . The first two are of special importance in that they are identified as the third member of a  $K=\frac{3}{2}$  positive-parity band (7.53,  $\frac{3}{2}^+$ ; 5356,  $\frac{5}{2}^+$ ; 113.01,  $\frac{7}{2}^+$ ) and a  $K=\frac{3}{2}$  negative-parity band (35.85,  $\frac{3}{2}^-$ ; 90.87,  $\frac{5}{2}^-$ , 167.82,  $\frac{7}{2}^-$ ) which form a basic key to the above-mentioned analysis. The main difficulty in applying the Nilsson model to  $\text{Sm}^{153}$  is that the experimentally derived level scheme suggests about twice as many rotational band heads below 500 keV as are suggested by the model. This problem is overcome by assuming that the  $\text{Sm}^{153}$  nucleus has two stable deformations rather than one. Although this assumption is suggested by theoretical calculations, it is difficult to prove. On the basis of the previous value of  $7982.7 \pm 1.8$  keV for  $\text{Sm}^{150}$ , the neutron binding energy of  $\text{Sm}^{153}$  was found to be  $5863.3 \pm 2.0$  keV.

#### ( $\text{He}^3$ , d) REACTION ON THE LEAD ISOTOPES

Nelson Stein,\* R. H. Siemssen,\* and B. Zeidman

Bull. Am. Phys. Soc. 12, 1066 (November 1967)

The ( $\text{He}^3$ , d) reaction on  $\text{Pb}^{206}$ ,  $\text{Pb}^{207}$ , and  $\text{Pb}^{208}$  has been studied with a 35-MeV beam from the Argonne cyclotron using a solid-state-detector particle-identification system. Angular distributions

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\* Yale University, New Haven, Connecticut.

from  $\text{Pb}^{208}$  were obtained from  $20^\circ$  to  $100^\circ$  with an energy resolution width of about 70 keV. The most prominent peaks in the spectra up to 4.5 MeV excitation in  $\text{Bi}^{209}$  are at 0.0, 0.90, 1.61, 2.84, 3.14, 3.67, and 4.46 MeV. The first five states agree with the locations of the single-particle proton states identified from the  $\text{Pb}^{208}(\alpha, t)$  reaction.<sup>1</sup> In particular, the state at 3.14 MeV, identified as the  $3p_{3/2}$  level,<sup>1</sup> is the most strongly excited state in the present experiment. This state does not appear in the previously published  $\text{Pb}^{208}(\text{He}^3, d)$  results.<sup>2</sup> The 3.67- and 4.46-MeV states are possible candidates for containing the  $3p_{1/2}$  strength which has not been located previously. The collective E3 multiplet excited strongly by inelastic scattering is seen very weakly at 2.6 MeV in the present  $(\text{He}^3, d)$  spectra. This excitation was not observed in the previous  $(\text{He}^3, d)$  work,<sup>2</sup> but it does appear with significant strength in the  $(\alpha, t)$  reaction.<sup>1</sup>

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<sup>1</sup>J. S. Lilley and Nelson Stein, Phys. Rev. Letters 19, 709 (1967).

<sup>2</sup>R. Woods, P. D. Barnes, E. R. Flynn, and G. J. Igo, Phys. Rev. Letters 19, 453 (1967).

American Physical Society  
Pasadena, 18—20 December 1967

# LEVEL STRUCTURE OF THE LOW-LYING EXCITED STATES OF $\text{Sc}^{46}$

H. H. Bolotin

Bull. Am. Phys. Soc. 12, 1123-1124 (December 1967)

The low-lying excited states of  $\text{Sc}^{46}$  populated by primary and secondary  $\gamma$ -ray transitions from the  $\text{Sc}^{45}(\text{n}, \gamma)\text{Sc}^{46}$  thermal-neutron-capture reaction were studied.  $\text{Ge}(\text{Li})$  detectors were used exclusively

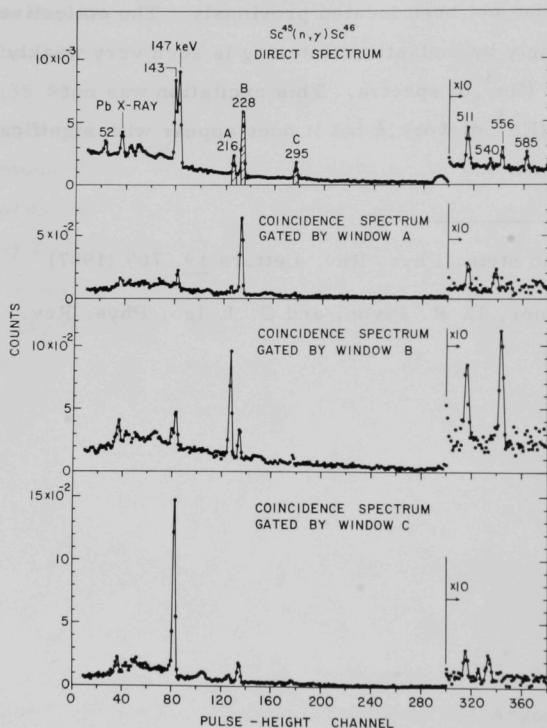


Fig. 15. Typical portions of the low-energy spectra in coincidence with the particular low-energy coincidence gates specified by the cross-hatched peaks of the singles spectrum shown in the upper portion of this figure. The three lower coincidence spectra shown have not been corrected for chance coincidences or for coincidence contributions due to those portions of the Compton distributions of higher energy transitions which underlie the respective coincidence gates used. The chance contribution can be estimated from a

comparison of the singles spectrum (whose shape the chance coincidence spectrum follows) and the magnitude of the 142-keV peak (which follows the decay of the noncoincident 19-sec isomeric level) in the coincidence spectra.

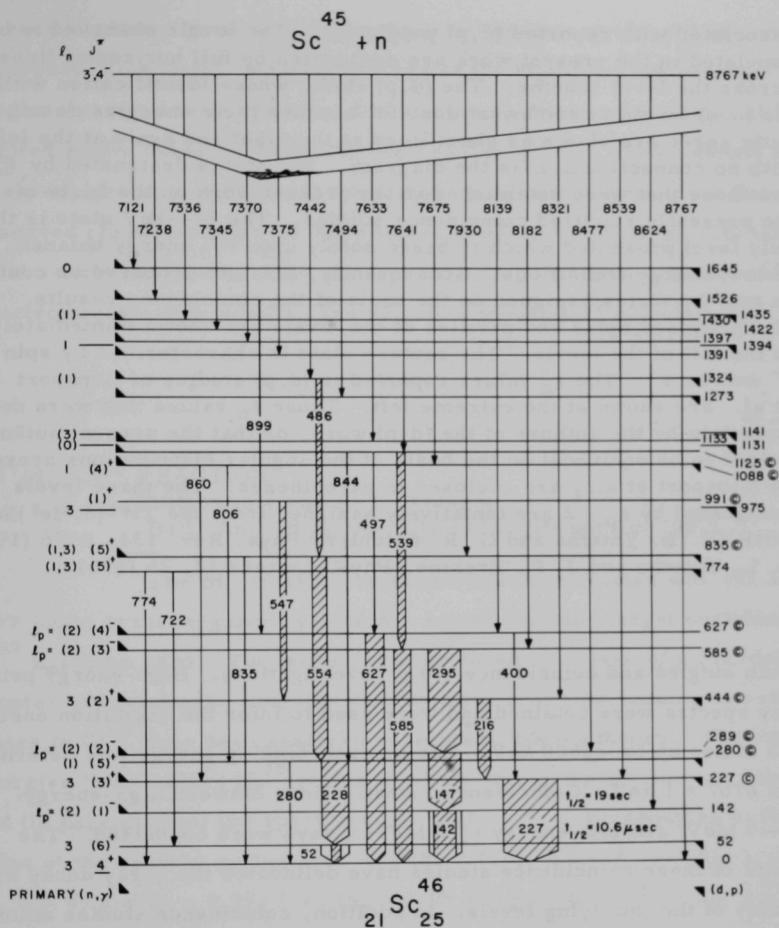


Fig. 16. Proposed level scheme of  $\text{Sc}^{46}$  deduced from the various coincidence and singles  $\gamma$ -ray investigations of the present work. This scheme was constructed without recourse to either the previously reported (n,  $\gamma$ ) bent-crystal-spectrometer results [P. Van Assche, U. Gruber, B. P. Maier, H. R. Koch, and O. W. B. Schult, Nucl. Phys. 84, 661 (1966)] or the (d, p) work of Rapaport et al. [J. Rapaport, A. Sperduto, and W. W. Buechner, Phys. Rev. 151, 939 (1966)]. The excitation energies are expressed in keV. Those levels marked on the left by upward-pointing flags are those that were observed to be populated by primary transitions from the capture state. Those levels marked on the right by downward-pointing flags are levels

associated with reported (d,p) population. The levels observed to be populated in the present work are designated by full horizontal lines across the level scheme. The (d,p) states whose identification with the (n, $\gamma$ ) levels is somewhat doubtful because their energies do not quite agree are shown as short lines at the right and again at the left, with no connection across the diagram. The states designated by © are those that were established in the present work on the basis of the presently reported coincidence studies. The 774-keV state is the only level presented which is based solely upon the energy balance of low-energy transitions. Consequently, it is not proposed as confidently as are the states assigned on the basis of the coincidence results. The proposed spins and parities of the levels are shown immediately to the left of the levels. The capture state is characterized by spin  $3^-$  and/or  $4^-$ . The  $\ell_n$  values reported in (d,p) studies of Rapaport *et al.* are shown at the extreme left. Those  $\ell_n$  values that were deemed uncertain by the authors of the (d,p) work, or that the present author judged to be equivocal on the basis of the angular distributions presented by Rapaport *et al.*, are enclosed in parentheses. The three levels designated by  $\ell_p = 2$  are tentatively assigned from the  $\text{Ti}^{47}(\text{d}, \text{He}^3)\text{Sc}^{46}$  work [J. L. Yntema and G. R. Satchler, *Phys. Rev.* **134**, B976 (1964); J. L. Yntema and J. R. Erskine, *Phys. Letters* **12**, 26 (1964)].

in both singles and coincidence  $\gamma$ -ray investigations. High-energy primary  $\gamma$ -ray spectra were obtained and were used to infer the excitation energies of 53 states up to  $\sim 2600$  keV. The neutron binding energy was determined to be  $8767 \pm 1$  keV. Coincidence investigations between high-energy ( $\sim 7-9$  MeV) and low-energy ( $\lesssim 2$  MeV)  $\gamma$  rays were conducted. The results of these coincidence studies have delineated the  $\gamma$ -ray decay modes of many of the low-lying levels. In addition, coincidence studies among the low-energy secondary transitions (Fig. 15) served to corroborate the high-low-energy coincidence findings and add other pertinent information about several additional low-lying states and the  $\gamma$ -ray transitions among them. These studies are the first known application of these high-resolution Ge(Li)-Ge(Li) coincidence studies employed in the field of slow-neutron capture  $\gamma$ -ray spectroscopy. The coincidence results have allowed a total of 23 low-energy transitions to be assigned between states up to

an excitation energy of 1324 keV. The combination of these data and high-resolution Ge(Li) detector studies of the high- and low-energy singles spectra have defined a level and decay scheme for a total of 57 excited states below an energy of 2600 keV (Fig. 16). This scheme differs in several important respects from those proposed previously. The observed characteristics of these states have been compared with the most recent charged-particle reaction studies, previous bent-crystal-spectrometer  $\gamma$ -ray results, and available theoretical calculations.

### $\text{Cl}^{37}(\text{d}, \text{t})\text{Cl}^{36}$ REACTION

N. G. Puttaswamy and J. L. Yntema

Bull. Am. Phys. Soc. 12, 1123 (December 1967)

The  $\text{Cl}^{37}(\text{d}, \text{t})\text{Cl}^{36}$  reaction has been studied with the 23.35-MeV beam of the Argonne cyclotron. A lead chloride target enriched in  $\text{Cl}^{37}$  has been used. The tritons are identified by means of a  $(\text{dE}/\text{dx})\text{-E}$  counter arrangement. Angular distributions of tritons leading to several states in  $\text{Cl}^{36}$  have been analyzed in terms of DWBA theory. The excitation energies (MeV) of the  $\text{Cl}^{36}$  states to which strong transitions are observed and (in parentheses) the spectroscopic factors  $S_\ell$  corresponding to the  $\ell$  value of the neutron pickup are: 0.0 ( $S_2 = 1.0$ ), 0.79 ( $S_2 = 1.4$ ), 1.16 ( $S_0 = 0.03$  and  $S_2 = 0.3$ ), 1.60 ( $S_0 = 0.05$  and  $S_2 = 0.3$ ), 1.95 ( $S_0 = 0.1$  and  $S_2 = 0.4$ ), and 2.50 ( $S_0 = 0.1$  and  $S_2 = 0.4$ )—the values of  $S_0$  and  $S_2$  for the latter four states are uncertain by a factor of 2. There is evidence for two groups of tritons corresponding to excitation energies of 2.68 and 2.85 MeV in  $\text{Cl}^{36}$ . The  $\ell$  values are consistent with known spins for the states in  $\text{Cl}^{36}$ . The spectroscopic factors are in reasonable agreement with the shell-model calculation of Glaudemans *et al.*<sup>1</sup>

<sup>1</sup>P. W. M. Glaudemans, G. Wiechers, and P. J. Brussaard, Nucl. Phys. 56, 548 (1964).

## MÖSSBAUER STUDIES OF K AND ITS COMPOUNDS

S. L. Ruby, P. K. Tseng, and D. H. Vincent\*

Bull. Am. Phys. Soc. 12, 1149 (December 1967)

The Mössbauer effect using the 29.4-keV gamma ray in  $K^{40}$  following  $K^{39}(n, \gamma)K^{40}$  has been observed by Hafemeister and Shera<sup>1</sup> in KF, KCl, and K. We have made measurements at 80°K with the compounds  $KN_3$ , KH,  $KNiF_3$ ,  $KCoF_3$ ,  $KO_2$ ,  $KC_8$ ,  $K_2S$  as targets with a KCl absorber. The data can be summarized at the present stage of analysis with (a) the backgrounds and  $f$  vary strongly from one case to the other, (b) quadrupole splittings and isomeric shifts are small if not zero, (c) the two antiferromagnetic perovskites showed no magnetic splitting below their Curie temperature. In order to investigate  $\delta r^2/r^2$  in  $K^{40}$ , we have carried out two careful center-shift measurements in  $K(4^\circ K)$  vs  $KCl(80^\circ K)$  and  $KF(4^\circ K)$  vs  $KCl(80^\circ K)$  combinations.

From the observed isomer shifts of KF as a function of temperature, we obtain an effective Debye temperature  $\Theta_M = 210 \pm 20^\circ K$ , where "effective" means that the value was recalculated to be pertinent to the  $\langle r^2 \rangle$  of the K atom alone. From specific-heat data on K metal, measured elsewhere, one finds  $\Theta_M = 90 \pm 10^\circ K$ . These rather wide limits mainly reflect the present rather inadequate state of the lattice-dynamic theory. From these temperatures the thermal shift between KF and K at 10°K, the temperature at which the measurements took place, is calculated to be  $-0.053 \pm 0.01$  mm/sec. The experimental result was  $-0.055 \pm 0.01$  mm/sec, so that only  $0.002 \pm 0.014$  mm/sec is left to be explained as due to the effect of finite nuclear size. Then by use of an appropriate value of the difference  $\Delta\psi^2$  between the wave functions of these nuclear states, the fractional change of nuclear radius is found

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\*University of Michigan, Ann Arbor, Michigan.

<sup>1</sup>D. W. Hafemeister and E. B. Shera, Phys. Rev. Letters 14, 593 (1965).

to be  $\delta\langle r^2 \rangle / r^2 = (1 \pm 5) \times 10^{-4}$ ; i. e., the upper limit is  $< 5 \times 10^{-4}$ .

As anticipated from a nuclear model, this is one of the smaller values yet measured for any nucleus.



### III. ABSTRACTS OF PAPERS ACCEPTED FOR PUBLICATION

#### A SHELL-MODEL STUDY OF THE ISOTOPES OF O, F, AND Ne

A. Arima, S. Cohen, R. D. Lawson, and M. H. Macfarlane  
Nucl. Phys.

The nuclei  $^{18,19,20}\text{O}$ ,  $^{18,19,20}\text{F}$ , and  $^{20}\text{Ne}$  are described in terms of the shell model within the configurations  $(1d_{5/2}, 2s_{1/2})^n$ ,  $n = 2-4$ . The residual nucleon-nucleon interaction is parameterized in terms of its two-body matrix elements, which are varied until a best fit to the spectra is obtained. The resulting wave functions are used to compute static and dynamic nuclear properties. In general, the model fits the known experimental data on spectra, transition rates, and static multipole moments quite satisfactorily. In particular, good agreement with experiment is obtained for the rotational spectrum of  $^{20}\text{Ne}$  and for the lifetimes of several of the states of its ground-state rotational band. Fitting the level properties of  $^{20}\text{Ne}$ , however, is found to impose on the interaction parameters few restrictions beyond those already implied by a successful treatment of the O and F spectra. Although 36 states are fitted with a 16-parameter potential, it is found that several of the two-body matrix elements are not very well determined. Those interaction parameters that are well determined are compared with the results of a recent reaction-matrix calculation. It is found that satisfactory over-all agreement with experiment can be obtained only if the  $1^+$  excited state of  $^{18}\text{F}$  at 1.7 MeV is omitted from the fitting procedure. Rough estimates suggest that a core-excited  $1^+$  state should occur at about this energy. Thus although the shell model with effective interaction can absorb large amounts of configuration impurity, it cannot do so successfully when the degree of configuration impurity in one of the states under consideration differs radically from that in its neighbors.

#### MEASUREMENT OF THE POLARIZATION OF THERMAL NEUTRON BEAMS OF MIXED VELOCITIES

S. H. Barkan, E. Bieber, M. T. Burgy, S. Ketudat, V. E. Krohn, P. Rice-Evans, and G. R. Ringo  
Rev. Sci. Instr. (January 1968)

We have tried three methods of measuring the polarizations of beams of thermal neutrons reflected from magnetized mirrors. These methods were based on (a) depolarizers, (b) a current-carrying

foil (Dabbs foil), and (c) a Stern-Gerlach magnet. The Stern-Gerlach method appears to be the most reliable; with reasonable care it is accurate to  $\pm 1\%$ .

# VIBRATIONS AND THERMODYNAMIC PROPERTIES OF HEXASULFUR

Joseph Berkowitz, W. A. Chupka, Edward Bromels,\* and R. Linn Belford\*

J. Chem. Phys. (December 1967)

Infrared and Raman spectra of Engel's sulfur  $S_6$ , including complete polarization data for solutions of  $S_6$ , provide assignments for the fundamental modes. Force fields that have been successful for  $S_8$  provide good agreement with the  $S_6$  spectra. A force model previously used for  $S_8$  is shown to be incorrect. Thermodynamic properties ( $H_T^\circ - H_0^\circ$ ,  $F_T^\circ - H_0^\circ$ ,  $S_T^\circ - S_0^\circ$ ) for gaseous  $S_6$  are tabulated from  $100^\circ$  to  $3000^\circ\text{K}$ . The spectroscopic values  $S_{400}^\circ$  (92.8 eu) and  $S_{298}^\circ$  (84.6 eu) are in excellent agreement with those derived from thermodynamic measurements.

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\* University of Illinois, Urbana, Illinois.

# SPEKTREN UND WINKELVERTEILUNGEN DER PHOTOELEKTRONEN VON ATOMEN UND MOLEKÜLEN

J. Berkowitz, H. Ehrhardt,\* and T. Tekaas\*

Z. Physik (1967)

The photoelectron energy spectra produced by the impact of  $584\text{-}\overset{\circ}{\text{A}}$  photons on the gases Kr,  $\text{H}_2$ ,  $\text{N}_2$ ,  $\text{O}_2$ , CO, NO, and several alkanes are reported. The angular distribution of photoelectrons corresponding to the simultaneous formation of specific electronic states of the ion have been measured in the range  $30^\circ - 130^\circ$ . A preference for electron ejection in the direction of light propagation is shown in the formation of the electronic ground states of  $\text{NO}^+$  and  $\text{O}_2^+$ . Both involve the ejection of an electron from a  $\pi_g$  orbital.

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\* Physikalisches Institut der Universität Freiburg, Germany.

The onset energies for the various electronic states have been obtained with a resolution of ca. 40 MeV. The relative transition probabilities for formation of various electronic states in a given molecular ion, as well as the Franck-Condon factors within specific states, have been obtained.

Similar experiments with the alkanes (methane, ethane, propane, and n-butane) reveal directly the existence of widely separated electron states (or groupings of states) in the ion, as well as the probability of forming these states. This energy distribution function, of vital importance to the study of the unimolecular decay of ions, could only be inferred previously by use of a questionable assumption.

#### MAGNETIC MOMENT OF THE FIRST EXCITED STATE IN $^{133}\text{Cs}$ BY THE MÖSSBAUER EFFECT

L. E. Campbell and G. J. Perlow  
Nucl. Phys.

The Mössbauer effect in an external magnetic field of 77.65 kG has been used to determine the magnetic moment of the first excited state in  $^{133}\text{Cs}$  at 81 keV. The result is  $\mu_{\text{ex}} = +3.44 \pm 0.02$  n.m.

#### HEAVY-PARTICLE EMISSION FROM THE REACTIONS $^{19}\text{F} + d$ AND $^{19}\text{F} + ^3\text{He}$

D. Dehnhard, D. S. Gemmell, and Z. Vager  
Nucl. Phys. (1967)

The reactions  $^{19}\text{F}(d, ^6\text{Li})^{15}\text{N}$ ,  $^{19}\text{F}(d, ^9\text{Be})^{12}\text{C}$ , and  $^{19}\text{F}(^3\text{He}, ^{10}\text{B})^{12}\text{C}$  have been studied at bombarding energies between 7.5 and 13.0 MeV. The heavy particles emitted were identified by a simultaneous analysis of particle energy and time of flight. Differential cross sections for the reaction  $^{19}\text{F}(d, ^6\text{Li})^{15}\text{N}$  have been measured at several bombarding energies in the range 9.0–12.5 MeV. Excitation functions for this reaction were measured at  $\theta_{\text{lab}} = 70^\circ$  and  $180^\circ$  between  $E_d = 7.5$  and 13.0 MeV. Angular distributions were measured for the  $^{19}\text{F}(d, ^9\text{Be})^{12}\text{C}$  reaction at  $E_d = 9.0$  and 12.0 MeV, and a  $180^\circ$  yield curve was measured between  $E_d = 9.0$  and 12.6 MeV. An angular

distribution for the  $^{19}\text{F}(^3\text{He}, ^{10}\text{B})^{12}\text{C}$  reaction was obtained at  $E(^3\text{He}) = 13$  MeV. The observations that in all cases the angular distributions show diffraction-like structure and the excitation functions do not fluctuate strongly indicate that a direct-reaction mechanism is dominant. However, attempts to fit the data with calculations based on the distorted-wave Born approximation and assuming pickup of an  $\alpha$  particle [for the  $(d, ^6\text{Li})$  case] or a  $^7\text{Li}$  [for the  $(d, ^9\text{Be})$  and  $(^3\text{He}, ^{10}\text{B})$  cases] were mostly unsuccessful.

# DELAYED PROTONS FOLLOWING $\text{He}^3$ REACTIONS WITH OXYGEN, SILICON, AND SULFUR TARGETS

R. W. Fink,<sup>\*</sup> T. H. Braid, and A. M. Friedman<sup>†</sup>  
Arkiv Fysik (1967)

Data on the spectra and lifetimes of beta-delayed proton activity from  $\text{Ne}^{17}$ ,  $\text{S}^{29}$ , and  $\text{Ar}^{33}$  are presented. The activities were produced by the  $(\text{He}^3, 2n)$  reaction at 33 MeV.

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<sup>\*</sup>Georgia Institute of Technology, Atlanta, Georgia.

<sup>†</sup>Chemistry Division.

# LINEWIDTH OF MÖSSBAUER ABSORPTION

Juergen Heberle

Nucl. Instr. Methods

The linewidth  $W$  has been computed for various absorber thicknesses. It is assumed that both the source and the absorbing material have the natural linewidth  $\Gamma$ . Then, for an absorber containing  $n$  nuclei (of the resonant species) per unit area, the formula  $W = 2\Gamma(1 + 0.1288t + 4.733 \times 10^{-3}t^2 - 9.21 \times 10^{-4}t^3 + 3.63 \times 10^{-5}t^4)$  approximates the computed values, where  $t = nf'\sigma_{\text{res}}$ . The values of  $W$  given by this formula are accurate to better than 0.15% for  $0 \leq t \leq 12$ .

## INFINITE SYSTEMS OF CLASSICAL PARTICLES

Amnon Katz

J. Math. Phys.

In this paper, infinite translation-invariant and periodic systems of classical particles are treated directly—not as limits of finite systems. A formalism of classical creation and annihilation operators that create and destroy classical identical particles at points of phase space is employed. By use of this formalism, classical dynamical variables are expressed without reference to the canonical coordinates and momenta of individual particles or to the number of particles. Different physical situations are described by different representations of the algebra of creation and annihilation operators. The concept of thermal equilibrium is generalized so as to be meaningful in infinite systems. Stationary states and thermal-equilibrium states for an infinite system of noninteracting particles (possibly in a periodic external potential) are exhibited explicitly.

THE GIANT DIPOLE RESONANCE EXCITED BY  $\alpha$  CAPTURE

L. Meyer-Schützmeister, Z. Vager, R. E. Segel, and P. P. Singh

Nucl. Phys.

We have studied the reactions  $^{24}\text{Mg}(\alpha, \gamma)^{28}\text{Si}$  from  $E_\alpha = 5.3$  MeV to 14.5 MeV,  $^{26}\text{Mg}(\alpha, \gamma)^{30}\text{Si}$  from 4.0 MeV to 13.5 MeV and  $^{28}\text{Si}(\alpha, \gamma)^{32}\text{S}$  from 7.0 MeV to 12.0 MeV. These  $\alpha$  energies lead into the region of the giant dipole resonance in the compound nucleus. The yield of  $\gamma$  rays  $\gamma_0$  leading to the ground state of the final nucleus was studied for each of the three targets; and for  $^{24}\text{Mg}(\alpha, \gamma)$  the radiation  $\gamma_1$  going to the first excited state was also studied with reasonable accuracy. The angular distributions of  $\gamma_0$ , which were measured in 100-keV steps over a wide range of energies for the  $^{24}\text{Mg}$  and  $^{26}\text{Mg}$  targets and at two energies for the  $^{28}\text{Si}$  target, showed a dominant electric-dipole transition. This indicates that the  $(\alpha, \gamma_0)$  reactions lead predominantly through the giant dipole resonance in  $^{28}\text{Si}$  and  $^{30}\text{Si}$  and most likely also in  $^{32}\text{S}$ . The gamma-ray yield, which was measured in steps of 30 or 100 keV over the energy ranges studied, exhibited strong fluctuations in each case. For a capture both in  $^{24}\text{Mg}$  and in  $^{26}\text{Mg}$ , statistical analysis of the fluctuations showed that the reactions proceed nearly 100% through compound-nucleus formation and that the average width of the compound-nucleus resonances is about

60 keV. The integrated cross sections of these three alpha-capture reactions led to the conclusion that formation of the giant resonance by alpha capture is strongly inhibited—even in cases in which the alpha capture is isospin allowed. This is expected since the giant dipole resonance is supposed to consist predominantly of particle-hole states. Earlier experiments on proton capture by  $^{27}\text{Al}$  had shown that only a small part of the giant dipole resonance in  $^{28}\text{Si}$  leaks into the more complicated nucleon configurations of the compound nucleus. The observation that this part of the giant dipole resonance in  $^{28}\text{Si}$  decays with comparable strength by a particle and proton emission indicates that it has a strong admixture of isospin  $T = 0$ .

#### GRAVITY-INDUCED ELECTRIC FIELD NEAR A CONDUCTOR

Murray Peshkin

Ann. Phys. (January 1968)

A new derivation of the gravity-induced electric field is given. The central idea of this treatment is a generalization of the Faraday cage idea. It is assumed here that the force on a test charge surrounded by a conductor is independent of the charge on the conductor and of external electric fields, even when the conductor is differentially compressed by gravity. Under reasonable phenomenological assumptions, it is shown that compression-dependent corrections to the gravity-induced field are negligible. Then, if the test charge has the same  $e/m$  as an electron, a shield against electric fields also serves as a shield against gravity. Whether the necessary assumptions apply to real conductors is not certain.

#### INTERNAL MAGNETIC FIELD AT AN ANTIMONY IMPURITY IN IRON OR NICKEL

S. L. Ruby and C. E. Johnson\*

Phys. Letters (December 1967)

This letter reports an improved value for the transferred hyperfine field at the diamagnetic impurity Sb in iron and nickel. One of the new experimental challenges to theorists in magnetism is the

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\* A.E.R.E., Harwell, Didcot, Berkshire, England.

values of these fields, since their explanation requires deep insight into the subtleties of the electronic interactions. In metals, as here, partial success has been achieved along the lines of a Ruderman-Kittel-Yoshida model of the localized  $3d\uparrow$  spin interacting with the conduction-band  $4s$  electrons. With the same impurity in insulators (e.g., in our measurements of Sb in spinels), a very different model is required.

#### STUDY OF THE (d, p) REACTION IN THE $1p$ SHELL

J. P. Schiffer, G. C. Morrison, R. H. Siemssen, and B. Zeidman  
Phys. Rev. (20 December 1967)

Angular distributions for the (d, p) reaction leading to bound states in the  $1p$  shell have been obtained at  $E_d = 12$  MeV for all stable targets. Spectroscopic factors obtained in distorted-wave Born-approximation (DWBA) analyses with average parameters are in surprisingly good agreement with those obtained in the shell-model calculations of Cohen and Kurath. The oscillating structure of the angular distributions at backward angles tends to be quantitatively reproduced by the DWBA calculations, although the amplitudes of the oscillations and the magnitudes of the backward cross sections are very sensitive to details of the calculations. J-dependent effects, similar to those found in heavier nuclei, but with some complications, are also found here.

#### FERROMAGNESIAN SILICATE ABUNDANCES IN BRONZITE CHONDRITES AS DETERMINED BY THE MÖSSBAUER EFFECT

E. L. Sprenkel-Segel and G. J. Perlow  
Icarus (1968)

The Mössbauer effect in  $Fe^{57}$  was used to investigate iron minerals in meteorites. The ratio of olivine iron to pyroxene iron (calculated from the absorption intensities and the recoilless fractions) was found to be  $1.6 \pm 0.2$  for the bronzite chondrites Collescopoli, Ochansk, and Oakley. The relative amounts of iron in olivine and pyroxene may be combined with the electron-microprobe analyses of iron and magnesium in the separate minerals to obtain the number of formula units of pyroxene relative to olivine in an unseparated meteorite sample. The similar abundance ratios of pyroxene to olivine

indicate that these meteorites were derived from a common parent ferromagnesian silicate reservoir. For each meteorite, the FeO content of the olivine-pyroxene system is given as calculated from the MgO content of the chemical analysis, the ratio of magnesium to iron in each silicate, and the relative amounts of iron in olivine and pyroxene.

# STUDY OF THE (d,p) REACTIONS ON $\text{Zn}^{64,66,68,70}$

D. von Ehrenstein and J. P. Schiffer  
Phys. Rev. (20 December 1967)

Angular distributions from the (d,p) reactions on  $\text{Zn}^{64,66,68,70}$  have been measured with 10.0-MeV deuterons from the Argonne tandem Van de Graaff accelerator. The energies, spins, parities, and spectroscopic factors of levels up to about 3.5-MeV excitation energy have been determined by use of distorted-wave Born-approximation calculations. Empirical J-dependence rules are used to distinguish between  $\frac{3}{2}^-$  and  $\frac{1}{2}^-$  states. The ground-state Q values of the  $\text{Zn}^{64,66,68,70}$  (d,p) reactions, determined within  $\pm 10$  keV, were 5.758, 4.827, 4.259, and 3.609 MeV, respectively. The sums of the spectroscopic factors are discussed briefly.

# THE REACTION $^{25}\text{Mg}(^3\text{He},d)^{26}\text{Al}$ AT 12 MeV

A. Weidinger,\* R. H. Siemssen,\* G. C. Morrison, and B. Zeidman

Nucl. Phys.

The  $^{25}\text{Mg}(^3\text{He},d)^{26}\text{Al}$  reaction was studied at  $E(^3\text{He}) = 12$  MeV by use of the Argonne tandem Van de Graaff and a broad-range magnetic spectrograph. All known states up to 4.2 MeV were observed in this experiment; but the doublets at 2.07 MeV and 4.20 MeV have not been resolved. For the 15 strongest transitions, angular distributions between  $5^\circ$  and  $25^\circ$  were measured. They all have characteristic  $\ell=0$ ,  $\ell=2$ , or  $\ell=0+2$  stripping patterns. The  $\ell=0$  admixtures in the angular distributions limit spins and parities to  $2^+$  or  $3^+$  for the states at 2.55,

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\* Yale University, New Haven, Connecticut.

2.92, 3.59, 3.68, and 3.75 MeV, for which no spins and parities were previously known. Spectroscopic factors have been extracted with the Oak Ridge DWBA code Julie. The results are discussed in the framework of the unified model.

#### J DEPENDENCE FOR $\ell=1$ NUCLEON TRANSFER

J. L. Yntema and H. Ohnuma

Phys. Rev. Letters (4 December 1967)

The J dependence for  $\ell=1$  nucleon-transfer reactions at an incident-deuteron energy of 23 MeV is qualitatively reproduced by distorted-wave calculations. Considerably greater damping of contributions from the interior of the nucleus is required than previously thought necessary in (d,p) reactions. This may imply that the energy dependence of the real potential for protons is stronger than the dependence previously obtained for neutrons.

#### SPEED OF THE $\Delta J=1$ , $\Delta T=1$ M1 TRANSITION IN $\text{Al}^{26}$

D. H. Youngblood, R. C. Barse, N. Williams, A. E. Blaugrund, and R. E. Segel

Phys. Rev. (20 December 1967)

The attenuated-Doppler-shift technique has been used to determine the mean life of the 1.059-MeV third excited state in  $\text{Al}^{26}$  to be  $(3.1_{-0.8}^{+1.1}) \times 10^{-14}$  sec. The state decays primarily to the  $J^\pi = 0^+$   $T=1$ , 0.229-MeV first excited state. The spin component in this pure M1 transition can be deduced from the analogous Gamow-Teller  $\beta$  decay from the  $\text{Si}^{26}$  ground state to the 1.059-MeV state in  $\text{Al}^{26}$ . The observed lifetime is only about half what would be predicted from the spin component alone. This indicates a strong orbital contribution which, in turn, implies a large  $(d_{5/2})^{-2}$  component in the wave function. A summary of M1 transitions whose spin components are known from analogous  $\beta$  decays is given. A mean life of  $(4.8 \pm 2.5) \times 10^{-14}$  sec was found for the second excited state of  $\text{Mg}^{26}$ .

1. The purpose of this report is to provide information on the results of the investigation conducted by the FBI on the activities of the [redacted] in the [redacted] area. The results are summarized in the following paragraphs.

## 1. SUMMARY OF THE INVESTIGATION

The investigation was conducted by the FBI on the activities of the [redacted] in the [redacted] area. The results are summarized in the following paragraphs.

2. The investigation was conducted by the FBI on the activities of the [redacted] in the [redacted] area. The results are summarized in the following paragraphs.

3. The investigation was conducted by the FBI on the activities of the [redacted] in the [redacted] area. The results are summarized in the following paragraphs.

## IV. PUBLICATIONS SINCE THE LAST REPORT

## PAPERS AND BOOKS

SPEKTREN UND WINKELVERTEILUNGEN DER PHOTOELEKTRONEN  
VON ATOMEN UND MOLEKÜLEN

J. Berkowitz, H. Ehrhardt,\* and T. Tekaat\*

Z. Physik 200, 69-83 (1967)PHOTOIONIZATION OF ETHANE, PROPANE, AND n-BUTANE WITH  
MASS ANALYSIS

William A. Chupka and Joseph Berkowitz

J. Chem. Phys. 47, 2921-2933 (15 October 1967)ELEMENTS OF THE BRUECKNER-GOLDSTONE THEORY OF NUCLEAR  
MATTER

B. D. Day

Rev. Mod. Phys. 39(4), 719-744 (October 1967)HEAVY-PARTICLE EMISSION FROM THE REACTIONS  $^{19}\text{F} + d$  AND  
 $^{19}\text{F} + ^3\text{He}$ 

D. Dehnhard, D. S. Gemmell, and Z. Vager

Nucl. Phys. A104, 202 (1967)NEUTRON PICKUP REACTIONS ON  $\text{Si}^{30}$ 

D. Dehnhard and J. L. Yntema

Phys. Rev. 163, 1198-1203 (20 November 1967)DELAYED PROTONS FOLLOWING  $\text{He}^3$  REACTIONS WITH OXYGEN,  
SILICON, AND SULFUR TARGETSR. W. Fink,<sup>†</sup> T. H. Braid, and A. M. Friedman (Chemistry)Arkiv Fysik 36, 471-475 (1967)BOUNDARY CONDITIONS THAT ENFORCE MACH'S PRINCIPLE IN  
GENERAL RELATIVITY

A. Katz

Nuovo Cimento B51(2), 502-513 (11 October 1967)

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\*Physikalisches Institut der Universität Freiburg, Germany.<sup>†</sup>Georgia Institute of Technology, Atlanta, Georgia.

## FORMULATION OF NEWTON'S SECOND LAW

Amnon Katz

Am. J. Phys. 35(9), 882-883 (September 1967)PHOTOIONIZATION OF THE  $CF_3$  FREE RADICAL

Chava Lifshitz and William A. Chupka

J. Chem. Phys. 47, 3439-3443 (1 November 1967)SPECTRUM OF HIGH-ENERGY GAMMA RAYS FOLLOWING THERMAL-NEUTRON CAPTURE BY  $Er^{166}$ 

W. V. Prestwich and R. E. Coté

Phys. Rev. 162, 1112-1118 (20 October 1967)COMPLETE  $(i_{7/2})^2$  SPECTRUM OF  $Sc^{42}$ 

J. J. Schwartz,\* D. Cline,\* H. E. Gove,\* R. Sherr,† T. S. Bhatia,† and R. H. Siemssen

Phys. Rev. Letters 19, 1482-1484 (25 December 1967)

## RADIATIVE-CAPTURE STUDIES OF THE GIANT DIPOLE RESONANCE

Ralph E. Segel

Science 158, 723-730 (10 November 1967)

## HIGH-SENSITIVITY NEUTRON-CAPTURE GAMMA-RAY FACILITY

G. E. Thomas, D. E. Blatchley, and L. M. Bollinger

Nucl. Instr. Methods 56(2), 325-337 (1967)J DEPENDENCE FOR  $\ell=1$  NUCLEON TRANSFER

J. L. Yntema and H. Ohnuma

Phys. Rev. Letters 19, 1341-1343 (4 December 1967)

## REPORTS AT MEETINGS

International Symposium on Organic Scintillators, Argonne National Laboratory, 20-22 June 1966

## TIMING WITH ORGANIC SCINTILLATORS

Frank J. Lynch

Mol. Cryst. 3, 168-169 (August 1967)

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\* University of Rochester, Rochester, New Jersey.

† Princeton University, Princeton, New Jersey.

International Nuclear Physics Conference, Gatlinburg, Tennessee,  
12-17 September 1966, edited by R. L. Becker and A. Zucker (Academic  
Press Inc., New York, 1967)

ENERGY DEPENDENCE AND SPIN DEPENDENCE OF THE  
NEUTRON STRENGTH FUNCTION

S. De Barros,\* P. L. Chevillon,\* H. Jackson, J. Julien,\*  
G. Le Poittevin,\* J. Morgenstern,\* F. Netter,\* and  
C. Samour\*

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AN INVESTIGATION OF NEUTRON PICKUP FROM  $B^{11}$

D. Dehnhard, G. C. Morrison, and Z. Vager

pp. 112-115

INTERMEDIATE STRUCTURE OBSERVED IN NEUTRON CROSS  
SECTIONS

A. J. Elwyn, J. E. Monahan, and F. P. Mooring

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PROPERTIES OF PARTIAL RADIATION WIDTHS IN  $^{196}\text{Pt}$

H. E. Jackson, J. Julien,\* C. Samour,\* A. Bloch,\*

C. Lopata,\* and J. Morgenstern\*

p. 829

SPECTROSCOPIC FACTORS FOR FORBIDDEN TRANSITIONS

Dieter Kurath

pp. 861-864

MEASUREMENTS OF MIXED  $p_{1/2}$ - $p_{3/2}$  (d,p) TRANSITIONS IN  
LIGHT NUCLEI

D. Kurath, G. C. Morrison, J. P. Schiffer, R. H.  
Siemssen, and B. Zeidman

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SHELL-MODEL CALCULATIONS

R. D. Lawson and J. M. Soper

pp. 511-525

NUCLEAR PHYSICS CONCEPTS RELATED TO ELEMENTARY  
PARTICLE PHYSICS

H. J. Lipkin

pp. 450-459

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\* Centre d'Etudes Nucleaires de Saclay, Saclay, France.

International Nuclear Physics Conference (cont'd.)

THE GIANT DIPOLE RESONANCE IN SOME SELF-CONJUGATE  
NUCLEI IN THE  $1s-2d$  SHELL

L. Meyer-Schützmeister  
p. 404

FREQUENCY OF SPURIOUS "INTERMEDIATE RESONANCES"  
IN RANDOMLY GENERATED CROSS SECTIONS

P. P. Singh,\* P. Hoffman-Pinther,\* and D. W. Lang  
pp. 249-251

In Mössbauer Effect Methodology (Proceedings of the Third Symposium,  
New York, 29 January 1967), edited by I. J. Gruverman (Plenum Press,  
New York, 1967), Vol. 3

THE MÖSSBAUER EFFECT IN  $Cs^{133}$

G. J. Perlow  
pp. 191-201

PRESENT STATUS OF EXPERIMENTS WITH  $Sb^{121}$

S. L. Ruby  
pp. 203-215

In High Energy Physics and Nuclear Structure, Proceedings of the Second  
International Conference, Weizmann Institute of Science, Rehovoth,  
27 February-3 March 1967, edited by Gideon Alexander (North-Holland  
Publishing Company, Amsterdam, 1967)

HYPERNUCLEAR SPECTROSCOPY

A. R. Bodmer  
pp. 60-87

In Fifteenth Annual Conference on Mass Spectrometry and Allied Topics,  
14-19 May 1967, Denver, Colorado (ASTM Committee E-14)

KINETIC ENERGY SPECTRUM AND ANGULAR DISTRIBUTION  
OF PHOTOELECTRONS FROM SOME ATOMS AND MOLECULES

J. Berkowitz, H. Ehrhardt,<sup>†</sup> and T. Tekaath<sup>†</sup>  
pp. 124-128

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\* Indiana University, Bloomington, Indiana.

<sup>†</sup> Physikalisches Institut der Universität, Freiburg, Germany.

Fifteenth Annual Conference on Mass Spectrometry and Allied Topics  
(cont'd.)

REACTIONS OF IONS PRODUCED IN SELECTED STATES BY  
PHOTOIONIZATION

W. A. Chupka  
p. 63

LATTICE EFFECTS ON THE EMISSION OF SECONDARY  
PARTICLES FROM METAL MONOCRYSTALS UNDER HIGH-  
ENERGY ION BOMBARDMENT

Manfred Kaminsky  
pp. 124-128

In Nuclear Research with Low Energy Accelerators, Proceedings of the  
Symposium, University of Maryland, 19-24 June 1967, edited by J. B.  
Marion and D. M. Van Patter (Academic Press Inc., New York, 1967)

ANALOG-STATE EXPERIMENTS

George C. Morrison  
pp. 275-309

Phenomena in Ionized Gases 1967: Contributed Papers, Eighth International  
Conference, Vienna, 27 August-2 September 1967 (Springer-Verlag,  
Mölkerbastei 5, A-1010 Vienna)

SLAB-MODEL THEORY OF ADMITTANCE OF HIGH-FREQUENCY  
PLASMOIDS

M. Hasan, A. J. Hatch, and J. Taillet\*  
p. 167

ADMITTANCE OF LOW-PRESSURE HIGH-FREQUENCY DISCHARGES

A. J. Hatch, R. J. Freiberg, S. V. Paranjape, and  
B. A. Tryba-Wolterbeek  
p. 166

Nuclear Physics Division of the American Physical Society, Madison,  
Wisconsin, 23-25 October 1967

GAMMA-RAY SPECTRA FROM  $\text{Si}^{28,29,30}(n,\gamma)\text{Si}^{29,30,31}$  REACTIONS

G. B. Beard and G. E. Thomas  
Bull. Am. Phys. Soc. 12, 1199 (December 1967)

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\* Office National d'Etudes et de Recherches Aerospatiales Chatillon-  
sous-Bagneux, France.

Nuclear Physics Division of the American Physical Society (cont'd.)

DETERMINATION OF SPINS AND PARITIES OF LOW-ENERGY STATES FROM AVERAGE NEUTRON RESONANCE-CAPTURE SPECTRA

L. M. Bollinger and G. E. Thomas

Bull. Am. Phys. Soc. 12, 1200 (December 1967)

EVIDENCE FOR INTERMEDIATE RESONANCE STRUCTURE IN THE SCATTERING OF NEUTRONS BY Fe

A. J. Elwyn and J. E. Monahan

Bull. Am. Phys. Soc. 12, 1186 (December 1967)

$K^{39}(\text{He}^3, \gamma)\text{Ca}^{41}$  REACTION

D. S. Gemmell, L. Meyer-Schützmeister, H. Ohnuma, and N. G. Puttaswamy

Bull. Am. Phys. Soc. 12, 1183 (December 1967)

SMALL-ANGLE SCATTERING OF NEUTRONS BY HEAVY NUCLEI

F. T. Kuchnir, A. J. Elwyn, A. Langsdorf, Jr., and

F. P. Mooring

Bull. Am. Phys. Soc. 12, 1187 (December 1967)

POLARIZATION AND DIFFERENTIAL CROSS SECTION FOR NEUTRONS SCATTERED FROM  $^{12}\text{C}$

R. O. Lane, A. J. Elwyn, F. P. Mooring, J. E. Monahan, and A. Langsdorf, Jr.

Bull. Am. Phys. Soc. 12, 1185-1186 (December 1967)

APPLICATION OF A SELF-INDICATION METHOD TO THE MEASUREMENT OF NEUTRON ABSORPTION, TOTAL CROSS SECTION, AND THE VARIANCE OF THE TOTAL CROSS SECTION

F. P. Mooring and J. E. Monahan

Bull. Am. Phys. Soc. 12, 1187 (December 1967)

THE J DEPENDENCE OBSERVED AT SMALL ANGLES IN THE  $(d, \text{He}^3)$  REACTION

H. Ohnuma and J. L. Yntema

Bull. Am. Phys. Soc. 12, 1188 (December 1967)

ENERGY LEVELS OF  $\text{S}^{36}$  AND  $\text{S}^{34}$

N. G. Puttaswamy and J. L. Yntema

Bull. Am. Phys. Soc. 12, 1182 (December 1967)

Nuclear Physics Division of the American Physical Society (cont'd.)

LEVEL STRUCTURE OF  $\text{Al}^{29}$

D. H. Youngblood, J. L. Yntema, and R. C. Bearer  
Bull. Am. Phys. Soc. 12, 1181 (December 1967)

American Physical Society, New York, 16-18 November 1967

CAPTURE-GAMMA-RAY SPECTRUM OF  $\text{Te}^{123}(n, \gamma)\text{Te}^{124}$   
AND THE ASSOCIATED ENERGY LEVELS IN  $\text{Te}^{124}$

R. P. Chaturvedi, D. Bushnell, and R. K. Smither  
Bull. Am. Phys. Soc. 12, 1064 (November 1967)

HFS OF THE SEVEN LOWEST ATOMIC LEVELS OF  $\text{Co}^{59}$ ,  
AND THE NUCLEAR GROUND-STATE ELECTRIC QUADRUPOLE  
MOMENT

W. J. Childs and L. S. Goodman  
Bull. Am. Phys. Soc. 12, 1046 (November 1967)

LEVEL SCHEME OF  $\text{Sm}^{153}$  BASED ON  $(n, \gamma)$ ,  $(n, e^-)$ , AND  
 $(\beta, \gamma)$  EXPERIMENTS

R. K. Smither, E. Bieber, T. v. Egidy, \* W. Kaiser, \*  
and K. Wien<sup>†</sup>  
Bull. Am. Phys. Soc. 12, 1065 (November 1967)

$(\text{He}^3, d)$  REACTION ON THE LEAD ISOTOPES

Nelson Stein, ‡ R. H. Siemssen, ‡ and B. Zeidman  
Bull. Am. Phys. Soc. 12, 1066 (November 1967)

American Physical Society, Pasadena, 18-20 December 1967

LEVEL STRUCTURE OF THE LOW-LYING EXCITED STATES  
OF  $\text{Sc}^{46}$

H. H. Bolotin  
Bull. Am. Phys. Soc. 12, 1123-1124 (December 1967)

$\text{Cl}^{37}(d, t)\text{Cl}^{36}$  REACTION

N. G. Puttaswamy and J. L. Yntema  
Bull. Am. Phys. Soc. 12, 1123 (December 1967)

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\* Technischen Hochschule München, Germany.

† Technischen Hochschule Darmstadt, Germany.

‡ Yale University, New Haven, Connecticut.

APS, Pasadena (cont'd.)

MÖSSBAUER STUDIES OF K AND ITS COMPOUNDS

S. L. Ruby, P. K. Tseng, and D. H. Vincent\*

Bull. Am. Phys. Soc. 12, 1149 (December 1967)

PHYSICS DIVISION INFORMAL REPORT

THE REACTION MATRIX IN NUCLEAR SHELL THEORY

Malcolm H. Macfarlane

Physics Division Informal Report PHY-1967B (September 1967)

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\* University of Michigan, Ann Arbor, Michigan.

## V. PERSONNEL CHANGES IN THE ANL PHYSICS DIVISION

### NEW MEMBERS OF THE DIVISION

#### Visiting Scientist

Dr. Lindsay J. Tassie, Australian National University, Canberra, Australia. Off-diagonal long-range order in superconductors. Returned to Argonne on 5 December 1967 for a period of two months.

#### Postdoctoral

Dr. Karl J. Wetzel. Neutron-capture gamma-ray studies using both the chopper and the "through tube" facilities at the reactor. Came to Argonne on 15 November 1967.

#### University User of the ANL Tandem

Mr. Edward Berkowitz, University of Notre Dame, South Bend, Indiana. Studies of energy levels in light nuclei. First came to use the machine on 18 December 1967.

Co-op Technician

Mr. Charles M. Jaffe, Antioch College, Yellow Springs, Ohio. Working with S. L. Ruby on dielectric measurements of ions in ice. Came to ANL on 3 October 1967.

CSUI-ANL Honor Students

Miss Sau Kwan Chung, Hollins College, Hollins College, Virginia.

Working with L. Meyer-Schützmeister on determination of the performance of a large 30-cm<sup>3</sup> Ge(Li) detector: its absolute  $\gamma$ -ray efficiency and its energy resolution. Came to ANL on 5 September 1967.

Mr. LeRoy Harding, Eastern Nazarene College, Wollaston, Massachusetts.

Working with G. T. Wood on  $\gamma$  and electron spectroscopy of Xe<sup>125</sup> decay. Came to ANL on 5 September 1967.

Mr. Paul McManamon, John Carroll University, Cleveland, Ohio.

Working with A. J. Hatch on high-frequency plasmas. Came to ANL on 5 September 1967.

Miss Joan Quinn, Emmanuel College, Boston, Massachusetts. Working with S. L. Ruby on isomeric shifts of complex ions. Came to ANL on 5 September 1967.

Technicians

Mr. Edwin Sinars returned to the Physics Division on 27 November 1967 to work with J. R. Wallace.

Mr. Allan J. Winn joined the Physics Division on 6 November 1967 to work with J. R. Wallace.

## LEAVE OF ABSENCE

Dr. John P. Schiffer left ANL on 1 November 1967 to go to the University of Rochester, Rochester, New York as a Visiting Professor of Physics. He will be working with the MP tandem. He expects to return to Argonne about 1 July 1968.

## DEPARTURES

Dr. David L. Bushnell, resident associate (OCUC affiliate, CSUI-ANL) from Northern Illinois University has been on the staff of the Physics Division since 1 February 1967. He has worked on gamma-ray spectroscopy, particularly for  $\text{Te}^{124}$ , with the 7.7-m bent-crystal spectrometer. He terminated at ANL on 8 September 1967 to return to Northern Illinois University.

Mr. Ellwood Hupke, scientific technician (senior), has been at Argonne since 2 April 1947. He terminated at ANL on 30 November

Mrs. Jacqueline Smith, clerk, has been at Argonne since 1 September 1965. She terminated at ANL on 2 October 1967.

Dr. Peter Williams, postdoctoral, has been on the staff of the ANL Physics Division since 24 October 1966. He has worked on negative-ion formation on heated metal surfaces. He terminated at ANL on 5 October 1967 to go to the Department of Physics, University of Manitoba, Canada.

#### DECEASED

Dr. Robert E. Coté joined the staff of the ANL Physics Division in 1954. He arrived not long after the reactor CP-5 went into operation and much of his career at Argonne was devoted to experiments at the reactor. He was first involved in the development of the fast-chopper time-of-flight neutron spectrometer and then in its use. Major areas of investigation were the behavior of the s-wave strength function for intermediate-weight nuclides, the cross sections of  $\text{Pu}^{239}$ , the  $\gamma$  rays from resonance capture of neutrons, and the total cross sections of the actinide elements. During the past few years, he devoted himself to a study of muonic x rays in collaboration with a group from the Carnegie-Mellon University. He died on 1 October 1967 as a result of an accident suffered during a family vacation.

ARGONNE NATIONAL LAB WEST



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